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**THE USE OF A GEOGRAPHIC INFORMATION SYSTEM
TO INVESTIGATE SOIL SLIP DISTRIBUTION AND
THE LAND USE CAPABILITY CLASSIFICATION
IN THE EAST COAST REGION, NEW ZEALAND.**

A thesis presented in partial fulfilment of the requirements
for the degree of Master of Applied Science
in Soil Science at Massey University

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ABSTRACT

The land of the North Island East Coast region has such a severe erosion problem that in some places the current land use cannot be sustained. The expansion of exotic forestry in the region will provide protection for the land, regional growth and development, and employment, but it also brings competition for good land.

The New Zealand Resource Management Act, 1991, aims to promote sustainable use of our resources and requires regulatory authorities to monitor the state of their natural resources and to follow the principles set in the RMA when developing land use policies.

Remotely sensed data provides a timely and accurate assessment of surface features. Aerial photography provides a better delineation of soil slip erosion than satellite imagery.

Geographic Information Systems facilitate the storage and display of resource information. Through manipulation of GIS data layers, relationships between the distribution of soil slip erosion following Cyclone Bola, 1988, and other physical factors are investigated. The density of soil slip increases with increasing slope angle to a maximum on slopes of 30° . The amount of soil slip depends on the underlying rock type with jointed mudstone having the highest density. Most soil slip erosion occurs on NE, N, NW, and E facing slopes, but the reason for this cannot be attributed to either slope angle or rock type.

The Land Use Capability classification is currently used by land use managers and planners to describe the land in terms of its limitation to productive uses. The detail of information in the New Zealand Land Resource Inventory LUC classification can be improved by incorporating more detailed slope angle and slope aspect information derived from digital contour data.

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CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

The New Zealand Resource Management Act , 1991 (RMA), requires the use of land to be managed in such a way as to ensure its potential to meet the reasonably foreseeable needs of future generations and to avoid, remedy or mitigate any adverse effects on the environment resulting from its use.

The ability of the land in the East Coast of the North Island (Figure 1.1) to sustain pastoral land use has long been questioned. The combined factors of easily eroded, tectonically tilted and crushed soft rocks and periodic high rainfall storms produce spectacular flooding and erosion. The results of such events are erosion of the pastoral hill slopes and inundation of the intensely cropped downstream flats by floodwaters and silt.

The mitigation and remedy of large scale erosion has been appreciated as being beyond the resources of the district with the formation of central government funded schemes such as the East Coast Project 1970, and the East Coast Forestry Project, 1993. These schemes recognise that certain classes of land do not have the capacity to sustain pastoral use and should be planted in production or protection forests to reduce their susceptibility to erosion.

The classification and control of land in terms of sustainable land use was the responsibility of the Catchment Boards until they were abolished in 1991. Soil conservation duties in the East Coast were incorporated into the restructured and resource limited Gisborne District Council (GDC). Because of the cost recuperation policies of the government, random land survey and research is no longer carried out. Land inventory mapping is completed only by interested parties for specific purposes. The only land use capability (LUC) information available for all of New Zealand is the

New Zealand Land Resource Inventory (NZLRI). The information contained in this land inventory is recommended for regional planning; it is often of too small a scale to be used for detailed land use planning.

In carrying out their duties as defined in the RMA, local authorities are faced with the need to be able to investigate the state of their natural and physical resources; to classify the land in terms of its land use capability at the management-unit scale; and to predict the effects of present or proposed land use on the immediate and downstream environment.

1.2 OBJECTIVES OF THE STUDY

This project investigates the usefulness of a geographic information system (GIS) and remotely sensed information in fulfilling these duties. Image analysis techniques enable the acquisition of information relating to the state of resources from remotely sensed data. This can be accomplished in much shorter time than land based surveys. Computerised geographic information systems facilitate the storage of large amounts of spatially referenced information which can quickly be retrieved and manipulated for display or analysis.

Emerald Hills station in the Te Arai River catchment (Figure 1.2) was selected for this project because it has good vehicle and foot access; it has a variety of lithologies which are detailed on a 1:10,000 scale soil and water conservation farm plan along with other physical attributes; and it sustained considerable soil slip erosion during Cyclone Bola.

Specific objectives of the project include:

- (1) the delineation of soil slip erosion on Emerald Hills station following Cyclone Bola, 1988;
- (2) the determination of any relationships between the distribution of that soil slip and site factors;
- (3) the investigation of the success with which the Land Use Capability mapping system describes the proneness of the land to soil slip erosion;
- (4) an attempt to improve the detail of the New Zealand Land Resource

Inventory, Land Use Classification.

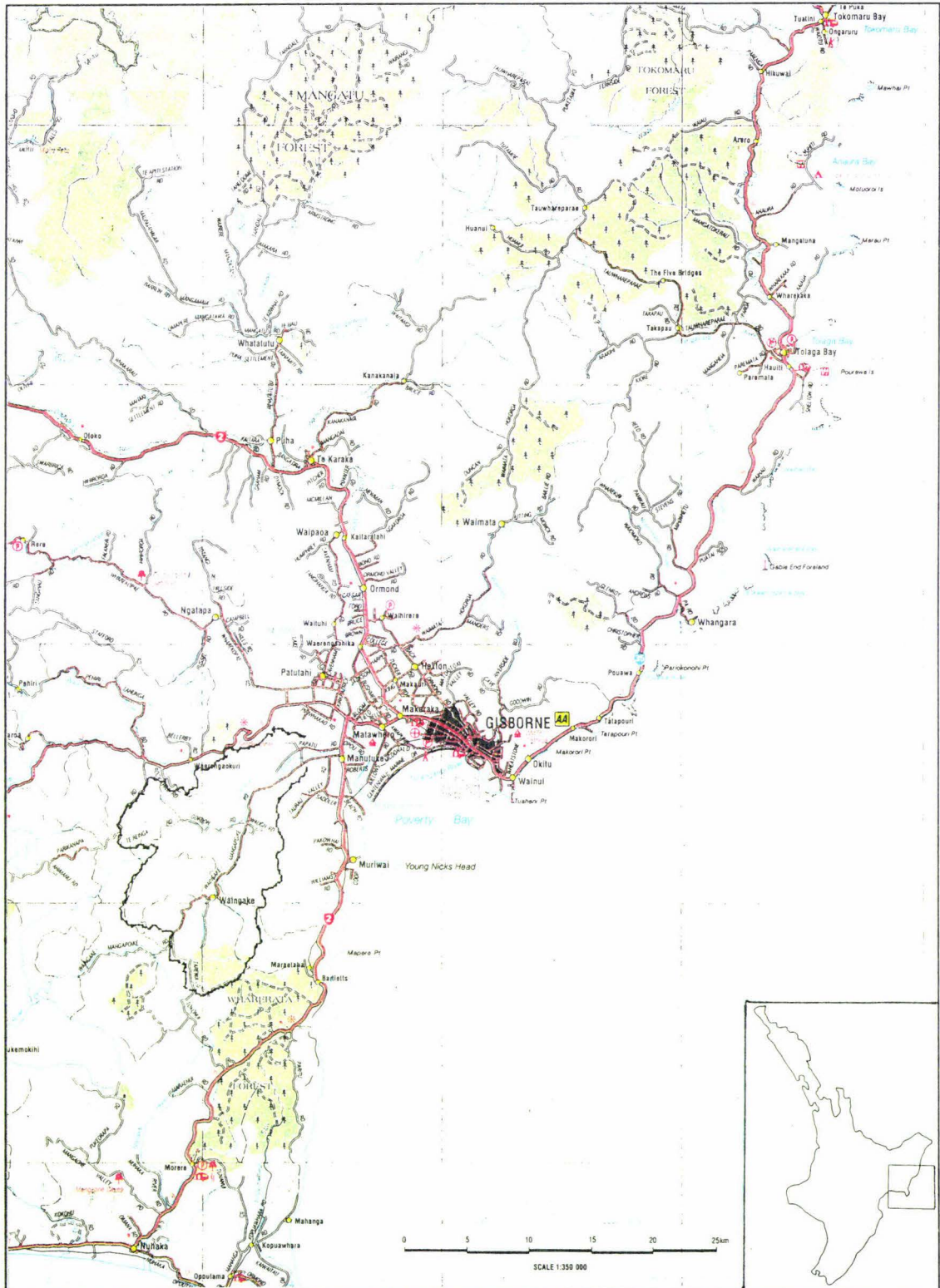


Figure 1.1 The location of this study in the East Coast Region, North Island, New Zealand.

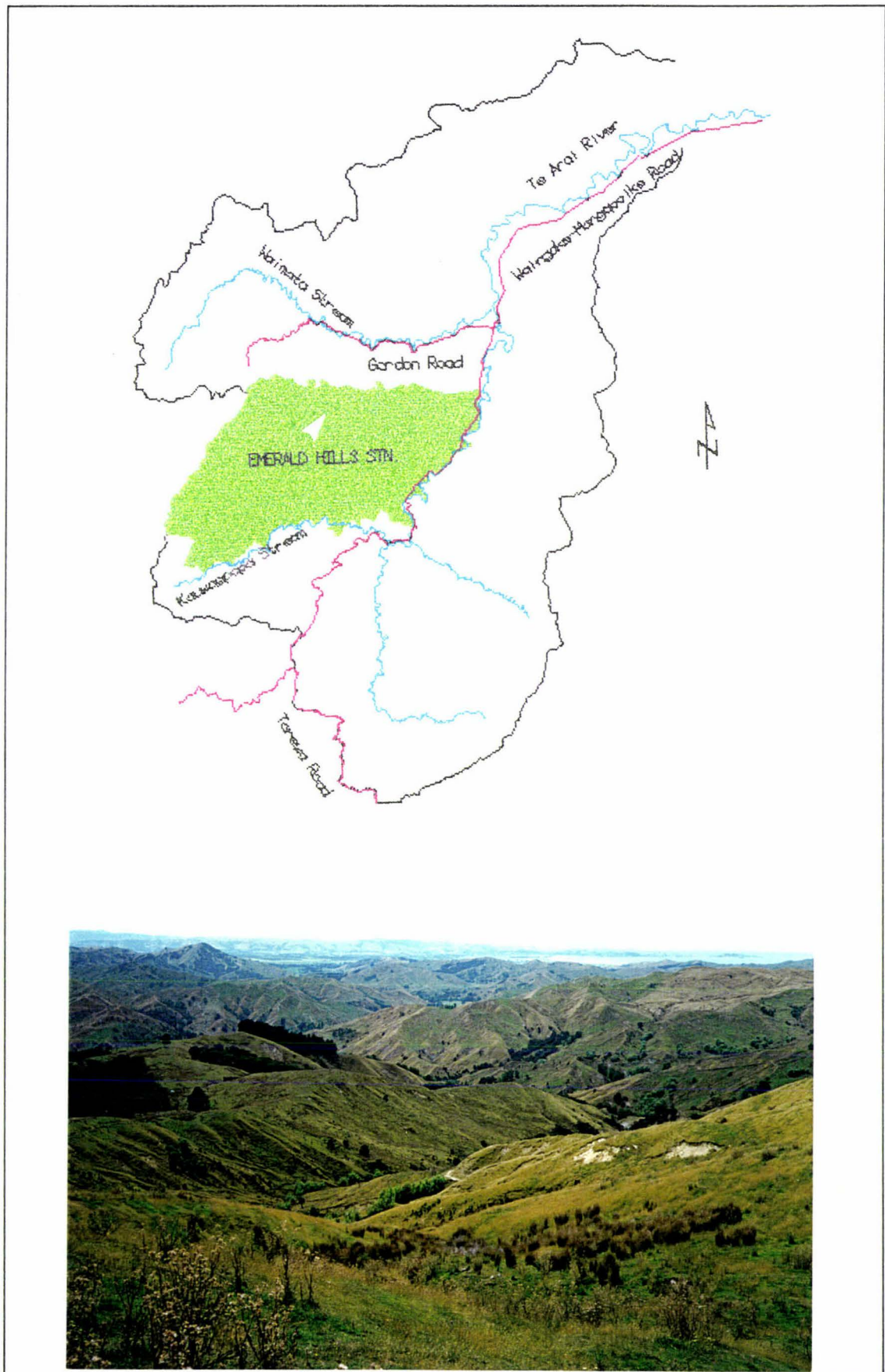


Figure 1.2 Emerald Hills station in the Te Arai River catchment. Photo view from farm down catchment to Gisborne.

CHAPTER II

HISTORY OF LAND USE, POLICIES AND ASSOCIATED PROBLEMS IN THE EAST COAST REGION

2.1 INTRODUCTION

The East Coast is on the active margin of a slab of continental crust, the Indian-Australian Plate. Young unconsolidated marine rocks have been faulted, tilted and elevated up to 1,000m above sea level, since the Miocene period, by pressure of the incoming subducting Pacific Plate. During the Quaternary, fluctuations in climate and sea level have added further instability leading to major cycles of natural geological erosion.

In recent times erosion rates have been among the highest in the world. This erosion and subsequent sedimentation has been occurring since well before the occupation by humans. After mapping recent soils on alluvium on the Gisborne Plains the dates of *c.*AD1650 and *c.*AD1450 were adopted for two periods of sedimentation by Pullar (1962). Erosional debris derived from the present hill country was deposited as a delta and later as a flood-plain to form the Poverty Bay flats. Using buried soils and tephra marker beds Pullar and Penhale (1970) described the infilling of the Gisborne Plains. From the time of the Taupo pumice eruptions (AD131) to *c.*AD1450 the rate of erosion of the hills adjacent to Gisborne City was low, and negligible infilling of the Gisborne Plains from *c.*AD1450 to *c.*AD1650 allowed the formation of Waiherere soils. Catastrophic erosion about AD1650 caused widespread infilling over the Plains and in particular in the Te Arai Valley, and since 1932 infilling of the Waipaoa River meander trough has been very high. The accelerated rate of erosion since the settlement of the area by Europeans, in the late 19th century, has in times of flood events threatened the actual survival of the current settlers.

As early as 1896 Sir James Hector, founder of the New Zealand Institute, warned that the elimination of the East Coast forest cover would result in widespread erosion. His concerns, and those of others went unheeded as property rights were exercised in the clearance of native vegetation for pastoral use. Without its protective cover the crushed and faulted landforms became exposed to the effects of a punishing climate. Hot, dry summers reduce vegetative cover, shrink and crack the surface predisposing it to the effects of periodic tropical cyclones which often bring high winds and very heavy rainfalls. These saturate the ground resulting in erosion which delivers vast quantities of debris into streams and rivers where it may accumulate or be carried downstream and deposited on fertile flat land, shorelines and the sea floor at the rivers' mouths.

Concern for the severity of erosion in New Zealand, especially in the East Coast region, has created a history of erosion control and land use policies and research projects, Table 2.1.

The effects of some land management practices on the lives of others have never been so seriously considered as they have in recent years. Storms since 1960, especially Cyclone Bola in 1988, have graphically demonstrated their effects. This, and the resultant requests for financial assistance by the land users, in a period of low economic wealth for all New Zealanders fuelled a debate on the need for wise and sustainable land use practices that resulted in the enactment of the Resource Management Act, 1991. Under this Act, local authorities are required to manage the use, development and protection of natural and physical resources in a way that not only satisfies present requirements but also ensures their sustainability to meet the reasonably foreseeable needs of future generations.

This chapter briefly outlines land use development and its effects in the East Coast. Some of the policies designed to assist development and mitigate erosion are also described.

DEVELOPMENT AND POLICIES AFFECTING THE EAST COAST

Late 1800s - early 1900s	Native forest and bush cleared for pasture
late 1800	Warnings of the effects of deforestation Govt. geologists advised Waipaoa riverbed had risen 2m in 15 yrs as a result of deforestation
1941	Soil Conservation and Rivers Control Act administered by the Soil Conservation and Rivers Control Council (SCRCC)
1944	Poverty Bay Catchment Board formed
1948	Flooding and large-scale soil erosion -Waipaoa River peak flow 3500 cumecs
1952	SCRCC adopt modified American Land Use Capability Classification for soil and water conservation plans, catchment control schemes and regional planning.
1960	Exotic forest plantings began at Mangatu
1963	SCRCC set up a technical committee of inquiry into conservation problems
1967	Resultant report titled "Wise Land Use and Community Development" - referred to as the "Taylor Report" or the "East Coast Project"
1967	First Land Use Capability surveys undertaken
1970	Co-ordinating committee set up to administer the East Coast Project released a district plan for the years 1970 - 1975
1975	Land Use Capability Worksheets completed
1976	East Coast Catchment Board (ECCB) set up a local study group to reconsider the proposals in the Taylor Report
1978	ECCB produced "Report of Land Use Planning and Development Study for the Erosion Prone Land of the East Coast Region" - known as the "Red Report"
1982	Protection/Production Forestry Grants introduced
1984	End of Forestry Grant applications
1984/85	New Zealand Forest Service disbanded, abolishment of government subsidies
1985	Ngatapa storm
1988	Cyclone Bola - Waipaoa R. peak flow 5300 cumecs
1989	East Coast Project Conservation Forestry Scheme
1990	Reorganisation of regional authorities results in dissolution of catchment boards, duties maintained by regional/district councils
1991	New Zealand Resource Management Act
1992	East Coast Forestry Project

Table 2.1 History of the development and land use policies of the East Coast

2.2 SETTLEMENT AND LAND CLEARANCE

Settlement of the East Coast by Europeans began near Gisborne (originally known as Turanga). This township was originally a whaling station because of the ease with which the small whaling ships could be navigated into the mouth of the Turanganui River. The whaling station later became a trading centre and supply base for the hill country stations, and is still the only large township in the region.

The native vegetation on the East Coast prior to European settlement followed a pattern determined primarily by altitude, soils and drainage. Fern and scrub associations existed on soils derived from pumice on the lower hills adjacent to the Poverty Bay flats with manuka (*Leptospermum scoparium*) present on areas of deeper pumice. Light bush dominated by titoki (*Alectryon excelsus*), puriri (*Vitex lucens*), kowhai (*Sophora tetraptera*), and karaka (*Corynocarpus laevigatus*) extended up the moister valleys; while heavy bush of podocarp and broadleaved species dominated the higher country. At the time of settlement heavy bush of podocarp and broadleaf types existed in the Te Arai catchment. The main timber types were kahikatea (*Podocarpus dacrydioides*) and pukatea (*Laurelia novae-zelandiae*) with totara (*Podocarpus totara*, *P. hallii*) and rimu (*Dacrydium cupressinum*) dotted about between tawa (*Beilschmiedia tawa*) and other species (Hamilton and Kelman, 1952). Early settlers describe this heavy bush as a 'black bush' and recall that the occurrence of 'hard red totara' trees was considered to indicate good soil. The luxuriance of the bush from a pioneer's point of view indicated the fertility of the area.

Early agriculture was established on the fertile flat lands with maize and wheat, and by 1858 there was a large export trade in ryegrass seed to Sydney out of the port at Gisborne. The potential of the region for sheep farming was soon realised and hill country settlement began in the 1870s. The population grew from 500 in 1879 to 2,300 in 1886 with large areas of land being 'broken in' by the burning of native vegetation followed by sowing with such grasses as ryegrass, cocksfoot and white clover. The development of large agricultural units proved very productive, with a high carrying capacity on fertile East Coast soils.

2.3 ACCELERATED EROSION

Within 30 to 40 years of clearing the native bush and forests, erosion in the East Coast became the most severe in the country; severe even by world standards (Cumberland, 1944; Campbell, 1946; Bishop, 1968). A marked change in the appearance of the country after heavy rainfall and subsequent flooding during December 1893 and January 1894 was noted by Hill (1896) with "...open and improved country seeming to have suffered most and bush country least." And once started, it accelerated. General opinion is that there was a gradual increase in the area affected by erosion up to 1936, and since then the rate of erosion and the area affected has increased rapidly (Hamilton and Kelman, 1952).

The problems associated with erosion not only affected the farmers in loss of soil and those nutrients contained within it (a legacy from the cleared native vegetation) leading to reduced carrying capacity of the land, but were also to the detriment of the settlers downstream. Large slumps, earth flows and other mass-movements appeared damaging roads and buildings; streams and rivers flooded during heavy rains endangering stock and people on the flats and in the townships. Silts were deposited on fertile flat lands and infilled the port threatening the future of shipping. Periodic flood events have covered considerable areas of the flats (Pullar, 1962).

2.4 CONFRONTING THE EROSION

The Soil Conservation and Rivers Control Act, 1941 was passed "... to make provision for the conservation of soil resources and for the prevention of damage by erosion, and to make better provision with respect to the protection of property from damage by floods." The Catchment Boards established under this Act recruited river engineers and trained soil conservators to implement schemes for the control of flooding and erosion. The Soil Conservation and Rivers Control Council also introduced a system of erosion control based on Land Use Capability surveys and farm plans which consisted principally of producing a map showing the land use capabilities, or limitations, of various parts of a farm. Erosion control measures were then integrated into management and financial plans for the whole property, often with financial assistance from the council for conservation measures.

In 1944, the Poverty Bay Catchment Board (one of the first Catchment Boards formed) was set up with one of its prime responsibilities being the stabilisation of the headwaters of the area, thereby safeguarding the alluvial flats of Poverty Bay. In 1948, the Board commenced a large-scale trial of counter-erosion afforestation which attempted to establish a tree cover of conifers on those catchment areas above eroding gullies in the upper Waipaoa catchment. These trials clearly showed that once a canopy had formed, runoff and erosion in the gully below were considerably reduced.

The Waipaoa River, with its headwaters in the Raukumara Ranges, and draining 216,700 hectares is the main river of the Poverty Bay flats. Following large floods in 1948 and 1950 a flood control scheme was sought for the Waipaoa River to protect the flats, the only substantial area of flat land in the region, and Gisborne city from further flooding. The scheme consisted of three river diversions involving a channel shortening of three kilometres, together with a system of parallel stopbanks designed to accommodate a '100 year' flood flow of 4,400 cumecs (the 1948 flood peak flow having been estimated as 3,900 cumecs). These measures would safely contain the flood waters of consequent storms including the 1985 Ngatapa storm which had a peak flow of 4,800 cumecs.

During Cyclone Bola, in 1988, there were some minor overflows, and in many places only 50 millimetres of freeboard. The river had a peak flow of 5,300 cumecs, 43% greater than the 1948 flow and 20% greater than the predicted '100 year' peak flow. In contrast the normal summer flow of the river is 10 cumecs (Singleton *et al.*, 1989).

The Catchment Board realised that flood control measures alone could not succeed without controlling the land degradation and erosion upriver. In 1955, at the request of the Board, the Soil Conservation and Rivers Control Council set up a special committee to report on remedial measures. Based partly on the success of the tree planting trial referred to above, it recommended that the worst of the eroded areas in the Waipaoa catchment, about 2,500 hectares, should be afforested. This was to become the basis of Mangatu Forest, for which planting began in 1960 (Allsop, 1973).

For approximately twenty years the Catchment Board co-operated with farmers to implement conservation works on farms principally involving tree planting, damming and drainage. However, by 1963, recognising that large-scale erosion control was beyond their resources the Catchment Board issued a report that this could only be controlled by massive reafforestation, which led to the Taylor Enquiry.

2.5 THE TAYLOR REPORT

In July 1963, the Soil Conservation and Rivers Control Council set up a Technical Committee of Enquiry to investigate the conservation problems of Poverty Bay - East Coast districts and to make recommendations on a comprehensive control programme. This report was published under the title 'Wise Land Use and Community Development' (SCRCC, 1967) but is colloquially referred to as the 'Taylor Report' after the chairman of the Committee, N.H. Taylor, a founding Director of N.Z. Soil Bureau. The Committee recognised the exceptionally severe land erosion and associated social and economic problems of the region which they felt required urgent large scale remedies. The costs of dealing with the erosion problems were of such magnitude that the farming community alone could not economically support them.

Two zones were recognised and separated by a "blue line", one containing the worst erosion and highest potential for further erosion - termed the "critical headwaters area"; and the other being the balance of the district - referred to as the "pastoral foreland".

1. The "critical headwaters area" of 140,000 hectares, consisted of the most eroded and erodible land in the headwaters of streams and rivers underlain mostly by crushed argillite and greywacke rocks.
2. The "pastoral foreland area" of 485,000 hectares, comprised the easier less eroded land underlain by mudstone, sandy mudstone and argillite.

The Committee recommended that in order to control accelerated erosion and to ensure maximum enduring productivity from the Poverty Bay - East Coast District the "critical headwaters" be recognised as land needing the protection of a forest cover and that this area be progressively acquired and planted with dual purpose forests designed

to provide effective erosion control combined with maximum productivity. The Committee also recommended that the Poverty Bay Catchment Board's policy of farmer co-operation be continued in the "pastoral foreland" and that the soil conservation programs be expanded with more prominence being given to the treatment of whole catchments using preventative erosion control work and conservation farm plans. The whole of the Te Arai River catchment area fell within the pastoral foreland.

2.6 THE EAST COAST PROJECT, 1970

A Co-ordinating Committee was set up as a result of the Taylor Report. In 1970 it released a district plan for the years 1970-1975, called the East Coast Project. It recommended that 7,000 hectares of new forest be planted in the critical headwaters area by the 1973/74 planting season along with increase in annual planting in State forests in the East Coast.

The Taylor Report envisaged economic revival for the area with employment in forest planting, road building, port development and tourism resulting in expansion of the townships. However, land acquisition and forest planting was slow and not until 1973 was the planting target of 2,000 hectares a year exceeded.

There was anxiety from farmers behind the "Blue Line" who felt they would be forced off their land. There was also criticism of the "no compromise" stance of the Report in delineating the "Blue Line" because they felt that the potential of much of the land behind the "Blue Line" had been underestimated.

2.7 RED REPORT

It became appreciated that the simple zoning between the Pastoral Foreland and the Critical Headwaters Area (the "Blue Line") was too general. In 1976 an interdepartmental committee was formed by the Poverty Bay Catchment Board to:

- investigate modifications required for implementing the recommendations of the Taylor Report;
- recommend best long-term use of different areas of land in three

- categories; large scale afforestation, farm scale afforestation and farming.
- make recommendations on planning and administration policies and practices that should apply at a regional level so as to reasonably achieve a desired pattern of land use within 50 years.

The committee produced "The Report of Land Use Planning and Development Study for Erosion Prone Land of the East Coast Region, 1978" (PBCB, 1978). Informally referred to as the "Red Report", this report recommended that the principles of the Taylor Report be re-affirmed and it redefined areas requiring soil conservation works based on the capability of the land to sustain long term use.

It developed four categories referred to as the Gisborne District Council Erosion Categories which describe sustainable land use capabilities (Table 2.2).

<u>Gisborne District Council Erosion Categories</u>		
	<u>Recommended Use</u>	<u>LUC</u>
<u>Category 1</u>	(a) Arable Farming	Classes II & III
	(b) Arable & Pastoral Farming	Classes IV & VI
<u>Category 2</u>	(a) Conservation Farming & Farm Scale Forestry	Units VIIe 1, 2, 5, 7 & VIIw
	(b) Conservation Farming, Farm Scale and Large Scale Forestry on some areas	Units VIIe 3, 4, 6, 8 19 & 21
<u>Category 3</u>	(a) Large Scale Production Forest (low priority for protection)	Units VIIe 9, 10, 11 & 17
	(b) Large Scale & Farm Scale Protection\Production Forest (moderate priority for protection)	Units VIIe 12, 14, 20
	(c) Large Scale Protection\Production Forest (high priority for protection)	Units VIIe 13, 15, 18
<u>Category 4</u>	Protection Forest	Class VIII

Table 2.2 Description of Gisborne District Council Erosion Categories

These categories have been used in successive district plans to advise land use policies. The Report recognised that the Land Resource Inventory and Land Use Capability information prepared by the Ministry of Works and Development (NWASCO, 1979) was valuable resource information but that it was more suited to indicative regional planning, while more detailed LUC surveys were necessary for farm scale land use planning. The Report also recommended that the Poverty Bay Catchment Board increase its annual programme of farm scale land use capability surveys; that the Board vigorously promote conservation farming methods, predominantly on category 1 and 2 land, afforestation in association with other conservation works in small areas of category 3 and appropriate category 2 land; and encourage the private sector to adhere to recommended land use policies and where appropriate, be given financial support to carry out afforestation of category 3 land.

The Red Report concluded:

"The East Coast is one of the few areas in New Zealand where there need be no competition with pastoral and forestry interests. There is ample scope for development in farming and forestry. A balanced regional land use and development policy will achieve this."

2.8 PRODUCTION FOREST DEVELOPMENT

Mangatu Forest was initiated to stabilise the severely eroding land of the Mangatu station. Planting began in 1960 and by 1970 about a million trees per year were being planted which had a significant effect on the labour force in the area (predominantly Maori). Within five years of the beginning of the Mangatu project the population within close proximity had increased by 44 percent. In all, a total of 36,000 hectares of the more severely eroded hill country was planted at Mangatu, other state forests and farm conservation works. In the mid-1970's the East Coast Project was abandoned because, even with harvesting, it did not promise a financial return. During the 1970's and 1980's afforestation by the New Zealand Forest Service continued along with forest plantings and on-farm conservation works by the East Coast Catchment Board, but it slowed after tax deductions for forest planting were disallowed from 1984, and after the Forest Service was disbanded in 1986/87. However, the impact of Cyclone

Bola, in 1988, would show the physical value of forests foretold by so many people in the past, and that forests should not be valued by financial return alone. It was particularly noticeable that Mangatu forest escaped with only minor damage. During the 1980's the economy of the East Coast plummeted. The revenue from farms was low as a result of droughts, low wool prices and the removal of subsidies for fertiliser and farm improvements. This and the cessation of forest planting was having a detrimental effect on employment and economic welfare in the region. Then in March, 1988 the East Coast region experienced a greater than 100 year return storm.

2.9 CYCLONE BOLA

In early March, Cyclone Bola formed in the Pacific Ocean and moved across the Fijian Islands, west to Vanuatu, south to Raoul Island in the Kermadecs, and then southwestwards to New Zealand. Just north of New Zealand the Cyclone met an eastward-moving anticyclone in the Tasman Sea and came to a virtual halt. At 12 noon on Monday, March 7th, the centre of Cyclone Bola was 200 kms northwest of North Cape, trapped between the anticyclone and another anticyclone forming to the east.

The cyclone, heavily laden with moisture from the humid tropics, began to release its load onto Northland, the Coromandel Peninsula and the East Coast of the North Island resulting in torrential rain and storm-force winds as it moved southwest towards the west coast around Taranaki.

The Hawkes Bay and East Coast catchment authorities studied the weather forecast, checked rainfall and river level measuring systems and began issuing flood warnings.

In the East Coast region, over the 96 hour period from 6th to 9th of March, it rained almost continuously. Up to 900mm of rain was recorded in the higher catchment inland of Tokomaru Bay towards the Raukumara Range, 600mm was common, with 500mm widespread. These figures were the highest rainfall recorded since records began in 1876. The estimated return period of this event was greater than 100 years (B Turnpenny, G.D.C. *pers comm.*). On average, 5,000 tonnes of rain fell on every

hectare of the region. In the Te Arai catchment the total rainfall during the storm was approximately one-third of the average annual rainfall, Figure 2.1.

A state of civil defence emergency was announced on the March 7th and lasted until the March 25th.

Whilst the Waipaoa River Flood Control Scheme contained most of the flood waters from its catchment, Cyclone Bola caused widespread landsliding and flooding over an area of 650 km² of the Raukumara Peninsula (Phillips *et al.*, 1990), and 12,000 km² of the North Island (Trotter *et al.*, 1989). Every road in the region was affected to some degree, many suffering severe damage. State highways between Gisborne and Wairoa, Waikaremoana and Opotiki were closed due to slips, washouts, siltation or the collapse of bridges. The railway line was impassable due to slips and an 80 meter dropout on the western approach to the Waipaoa River bridge, 10 kilometres from Gisborne. There were widespread losses to telephone and power lines. The water pipeline which runs through the Te Arai River valley and supplies Gisborne city with domestic water was blocked by debris and a large section was washed out by the swollen Te Arai River. This resulted in 10% of the city having no water for 3 days. Stormwaters inundated the sewerage system and a small number of houses in lower lying areas were flooded. Some residents in farming districts were isolated in flooded houses by road failures and slipped tracks, and were without adequate domestic water for 5 to 6 days.

Severe erosion occurred in hill country, especially the Tauwhareparae/Tutamoe area inland from Tolaga Bay, the hill country area south and west of Poverty Bay and the Tutira area of the Hawkes Bay. Some hill country properties lost up to 30% of their grazing area, but about 70% of damaged properties lost between 5% and 10%. Although between 60% and 80% of the damaged area has recovered quite quickly, the more severely eroded areas will take decades to recover (Singleton *et al.*, 1989). Landslide scars may recover 70-80% of the production of remnant forest soils over the first 20-40 years but there is no further recovery up to 100 years (Trustrum *et al.*, 1990). A study in the Waihora River catchment, revealed an increase in erosion

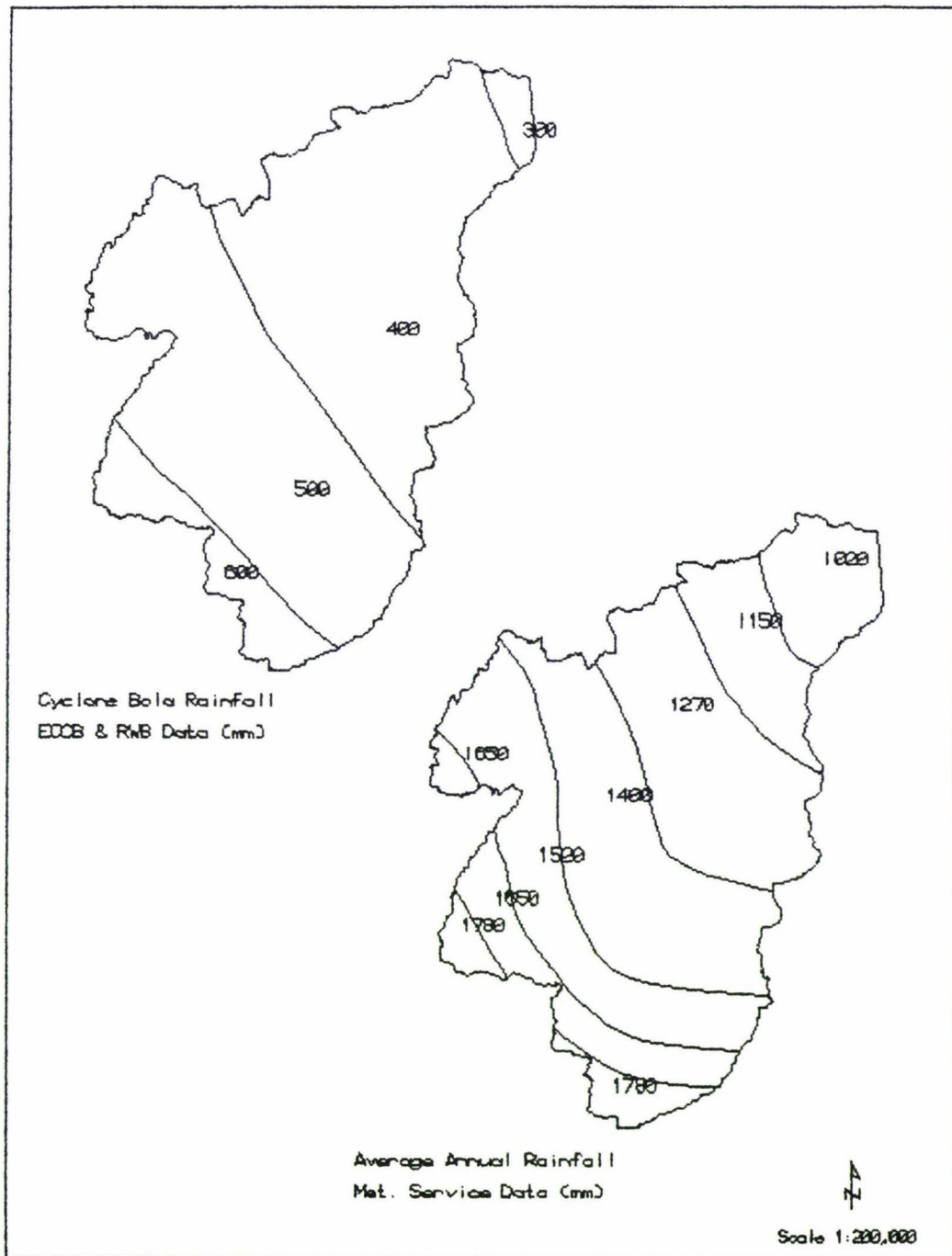


Figure 2.1 The distribution of rainfall during Cyclone Bola in the Te Arai River catchment compared with the average annual rainfall.

severity of 72% over the 1978 records (ECCB & RWB, 1988). This was a cause for concern because that level of erosion had taken 120 years since forest clearance to develop, (T. Freeman, G.D.C. *pers comm.* 1992).

Widespread erosion on steep hill surfaces resulted in the inundation of farmland on river terraces and flats by silts with severe siltation occurring to some extent on virtually all valley floors in the region, particularly the Hikuwai Valley. Siltation resulted in a loss of depth in Gisborne harbour with an estimated 75,000 cubic meters of infill. This restricted loading levels of ships with logs, meat, kiwifruit and maize. Dredging was required with an estimated cost of \$468,000.

Cyclone Bola caused in excess of \$NZ120 million damage to the North Island (Trotter *et al.*, 1989). A survey of one large catchment in the northern East Coast estimated that for every \$1 loss in on-site production sustained from Cyclone Bola, a further \$1.34 was spent on repairs to farm assets. There was also \$0.76 of downstream production loss and \$0.23 of repairs to downstream assets (Trustrum and Blaschke, 1992).

2.10 EROSION CONTINUES

The region has about 240,000 hectares of hill country of which 140,000 hectares is zoned as erosion category 2 land, having "moderate to severe" erosion. The remaining 100,000 hectares is zoned category 3 erosion land, having "extreme" erosion. Cyclone Bola-induced surface slipping on category 2 land destroyed much grazing and looked appalling yet it is the predominantly mudstone, category 3 land that has received the most attention by those concerned with the erosion problem.

Cyclone Bola served to remind us of the dynamic nature of the land surface. The land is continually increasing in height above sea level every year with uplift of 3mm/yr uplift along the Raukumara Range and 1mm/yr closer to the coast including the study area (Pillans, 1986). Deformational rates for the region, the Hikurangi subduction system, comprise plate convergence of 50mm/yr; with 40mm/yr contraction and 30mm/yr strike-slip motion (Walcott, 1978). This is resulting in a highly deformed landscape prone to erosional forces. Streams and rivers downcut with greater

gravitational power each year, soil productivity decreases each year as rains wash off the nutrient-containing topsoil leaving slow to heal patches on all slopes, yet still the land remains unclothed, unprotected. Erosion on the hill country of the East Coast is occurring constantly, Bola simply made it more obvious by condensing five years erosion into one (Trevor Freeman, G.D.C. *pers comm.*, 1993).

2.11 LAND USE INCENTIVES

2.11.1 Agricultural Incentives

Prior to 1985 an array of Government-funded incentives were available to companies and producers aimed at increasing agricultural production. Reasons for high assistance for the agriculture sector were twofold. Prices for major agricultural products, particularly meat, had been weak for a number of years and many domestic industries which provided the materials needed for agricultural production were heavily protected against competition from imports resulting in high costs to the farmer.

A Supplementary Minimum Prices scheme (SMP) was introduced by the Government in 1978. It was designed to create greater long-term confidence in the profitability of pastoral farming by establishing new minimum prices for meat, wool and milkfat for the coming season, and providing 'support payments' to cover any short fall in market returns. In 1982, 1983 and 1984 \$382m, \$382m and \$295m were spent on the SMP scheme in the East Coast region. Between 1971 and 1985, \$247m was also spent by the Government on fertiliser and lime subsidies and applications in the region, \$23m was spent on a land development interest subsidy and \$48m on a livestock incentive scheme (New Zealand Statistics Yearbooks).

These incentives did not take into account the suitability of the land for agricultural practices but encouraged the clearance of native vegetation and exposure of unstable surfaces resulting in severe and often large-scale erosion, for example the Mangatu slip.

N.Z. Statistics Department information shows a reduction on livestock numbers in the years following the Ngatapa and Bola storms (1985 and 1988). This would seem to

reinforce the opinion of many, that the land cannot sustain pastoral use. Farmers in the region however, prefer to place the emphasis for lowered stock numbers on a falling meat and wool market and the cessation of subsidies.

2.11.2 Forestry Incentives

Under the Forestry Encouragement Act, 1962, the Government made loans to local authorities towards the cost of establishing and tending new plantations and the maintenance of those already in existence.

In 1970, funding was extended to private landholders in the form of a grant equal to 50 percent of the qualifying costs (up to \$200 per year) of establishing and developing new approved forests. This grant was an alternative to the tax concession already available to income-earning forest companies.

Exotic forest plantings in New Zealand have increased steadily since 1950 (New Zealand Statistics Yearbooks). Plantings in the East Coast region increased steadily from 10,000 hectares in 1971 to 86,000 hectares in 1990. Since 1975 private tree plantings have been greater than plantings by the State.

2.12 EAST COAST PROJECT CONSERVATION FORESTRY SCHEME, 1990.

Since Bola, several schemes have been initiated by the Government following public and local body pressure to redefine long term sustainable land use in the region. The East Coast Project Conservation Forestry Scheme, administered in 1989 by the East Coast Catchment Board and subsequently, since local government amalgamation, by the Conservation Division of the Gisborne District Council, targeted 15,000 hectares of hill country with severe to extreme or potentially severe soil erosion problems. The Scheme applied to land upstream of Gisborne, the Poverty Bay flats and the Tolaga Bay flats. It offered a 95% subsidy to farmers to establish conservation forest. Central government would meet 66% of the cost (\$7 million spread over five years) and 29% would be met by district ratepayers.

The Catchment Board estimated that 104,000 hectares of land in the East Coast region required conservation forestry and set a five year target for the planting of 13,600 hectares specifically the more severely eroded areas in the "critical headwaters". Initially landowner participation was reluctant. Why commit scarce resources to a project with no guarantee that one can harvest the trees in the future? There was no comprehensive land use plan to indicate which land required a permanent vegetation cover and which land should be zoned as suitable for forest which can be harvested without compromising the down-stream economy.

To date a total of 9,000 hectares of conservation forest has been established with 67 percent of this on land with severe erosion (GDC categories 2 and 3), and 12 percent on land with moderate erosion which under certain circumstances can readily achieve severe status. The balance being comprised of the adjoining land up to stable fencelines. The Scheme has been successful in reafforesting land with severe erosional problems.

2.13 NGATI POROU FORESTS LTD

Another government initiative was specifically directed towards the multiple-owned land in the north. It offered government loans at favourable rates to companies willing to participate in joint ventures with the land owners. Ngati Porou Forests Ltd planted 600 hectares of forest in 1989 and continues planting today. However, in doing so they are removing mature manuka and kanuka which some contend is contrary to the objectives of the reafforestation strategies for the region. The removal of natural vegetation over 2 metres on Class VI or Class VII land in preparation for planting is subject to a Gisborne District Council resource consent under the Vegetation Removal and Earthworks Regional Plan.

2.14 EAST COAST FORESTRY PROJECT, 1993

In 1992, the Government announced a new forestry scheme with multiple objectives of commercial forestry, conservation forestry and regional employment. The Scheme, to be administered by the Ministry of Forestry, aims for the Government to fund the planting of predominantly radiata pine (*Pinus radiata*) on a total of 200,000 hectares

of the Gisborne/East Coast region over the next 28 years. The project targets NZLRI Class VII (GDC categories 2 and 3), land and therefore is designed to plant a mix of severely and moderately eroding or erodible land but excludes areas of natural forest. Clearance of established or substantially regenerated natural forest is counter to the project's objectives. The project places a restriction on the clearance of natural vegetation for forest planting funded under this project, "...No line cutting, gap clearing or total clearing of any indigenous tree species will be approved under the scheme." Emerging indigenous tree species are defined within the scheme as those over 50 cm in height at more than 50 stems per hectare that have reached or will reach 30 cm in diameter. Areas that do not meet GDC resource consent criteria on vegetation removal are not eligible for grant approval.

Although a successful tender is reliant upon a number of factors, a property with more than 60% of Class VII land is qualified to tender. To meet the projects conservation objectives of increased employment opportunities and financial return to the economy, high initial stocking rates are considered necessary. The units within Class VII are grouped according to a required initial stocking rate to qualify for tender-

Group A, requiring a minimum initial stocking rate of 1250 stems per hectare, includes units VIIe1, 2, 4, 6, 8, 9, 10, 11, 17, 19 & 21.

Group B, which has a minimum initial stocking rate of 1500 stems per hectare, includes units VIIe3, 5, 7, 12, 13, 14, 15, 16, 18 & 20.

Preference for funding is given to those tenders with a more intensive planting regime (more Group A land) (MOF, undated).

This scheme has already come under serious criticism as it is seen as a subsidy to forestry companies who are purchasing the better of the eligible land and receiving government funding for normal operational costs resulting in higher profits. As the world demand for timber increases it is argued that production forestry will of its own accord become more widespread in the region and that Government initiatives should be targeted more directly at the most erodible land; *i.e.* that which contributes most to

sediment loading of streams and is not desired by forestry companies because of its difficult terrain.

CHAPTER III

DESCRIPTION OF THE STUDY AREA

3.1 FEATURES OF THE STUDY AREA

The Te Arai River catchment occupies an area of 19,000 ha, located approximately 25 kilometres south east of Gisborne, Figure 1.1. Altitudes in the catchment range from 30m along the river flats to 718m at Te Rimuomaru in the south and 708m at Parikanapa in the west. There are small areas (c.10% of the catchment area) of flattish land along the river, which expands towards the mouth of the catchment, that represent infilling of previous downcutting episodes within the physiography. Most of the catchment is composed of moderately steep to very steep slopes. About 65% of the land is of 8° to 25° slope and 13% has a slope of between 26° and 35°. The catchment is drained by the Te Arai River and its tributaries which flow into the Waipaoa River 4km inland from its mouth.

The catchment has been settled by European farmers since the mid-1800's. Extensive bush-clearing for conversion to pasture occurred around the turn of the century and until 1994 the catchment was predominantly in pastoral vegetation except for small (less than 100 ha) areas of conservation and production forestry, and an 1,100 ha water supply bush reserve at the head of the catchment. Intensive production on the river flats downstream includes viticulture, citrus orchards and market gardening. Te Arai station, 10,691 acres, was the first property to be developed in the catchment. Farmed by Charles Westrup from 1867, it was later leased by John Clark of Opou and settled by ballot in 1908. Emerald Hills station (Figure 1.2) has been farmed by the Parker family since 1898. In 1994, Emerald Hills and Y-wury sheep and cattle stations were sold in 1994 to Forest Enterprises Ltd. Planting of *Pinus radiata* on these properties, about 3,500ha within the catchment, commenced in the same year.

3.2 PHYSIOGRAPHY

3.2.1 Tectonic Setting

The study area lies within the East Coast Fold Belt, east of the Wairoa syncline. Much of this region has been subjected to uplift of about 3mm/yr (Pillans, 1986) during the last two million years (Quaternary). Broad synclinal and anticlinal folds have been faulted and refolded to tighter folds along a north to northeast trend. This structural deformation characterises the Fold Belt and determines the rock outcrop patterns. The anticlines are asymmetrical; with the longer and shallower limbs dipping to the west.

Lithologies of the East Coast region are predominantly Cretaceous greywackes and argillites, and Tertiary sandstones, mudstones, argillaceous limestones and bentonitic clay shales. During the Cenozoic tectonic movements resulted in highly incompetent Cretaceous bentonitic deposits and claystones being intensely crushed. More porous but stronger Tertiary sandstones and mudstones lie above these crushed rocks. Quaternary tectonic movements, eustatic sea levels changes and periodic tephra showers have subsequently influenced the shaping of the present landscape.

3.2.2 Geological Structure of the Te Arai River Catchment

The catchment extent is controlled by the western axis of Mangaone-Waingake uplift in the west; by the Rerepe anticline in the south and east; and by the Waerenga-O-Kuri fault complex in the north, Figure 3.1. The Mangaone-Waingake uplift is a large compound anticline trending roughly NE-SW from the north end of the Morere anticlinorium of Hawkes Bay to the Waimata River valley where it terminates against a large cross fault; the Waimata Valley Fault (Brown, 1961). This western axis of the Mangaone-Waingake anticline forms the fault controlled eastern flank of the Wairoa Basin. The Rerepe anticline is an extension of a structural platform which comes off the northwest flank of the Morere anticline. Between the Mangaone-Waingake anticline and the Rerepe anticline the surface dips to the Waingake-Te Arai synclinal. The Te Arai River roughly follows its direction. The syncline is broad, low dipping and simple, in contrast to the anticlines which are steeply dipping, asymmetric and faulted. This asymmetry fits the regional pattern of steeper eastern flanks and long low western flanks. The latter are well defined by sandstone strike ridges and dip slopes.

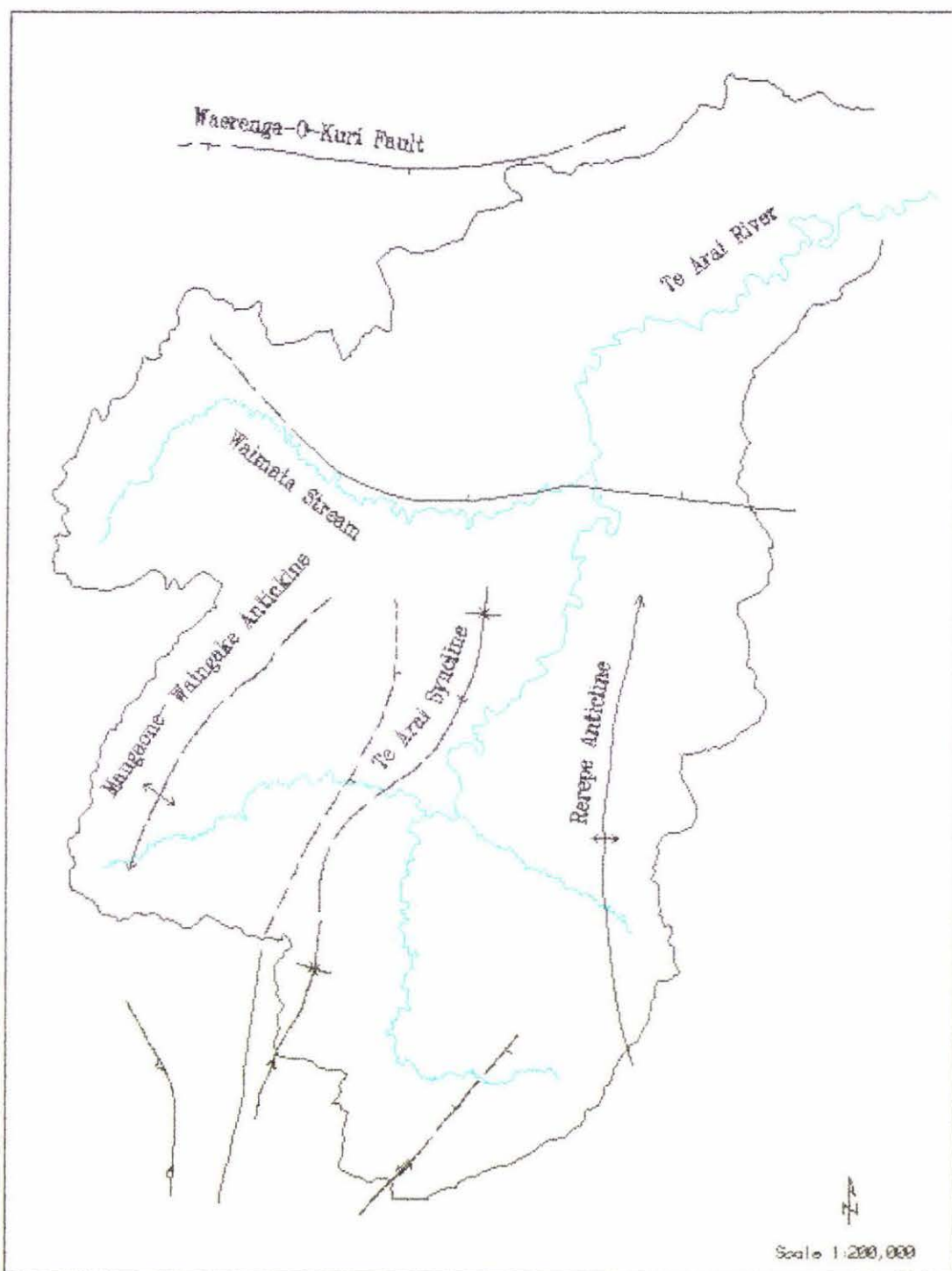


Figure 3.1 Geologic structure of the Te Arai River catchment, from Brown (1961)

3.2.3 Lithologies of the Te Arai River Catchment

All the lithologies of the study area are marine sedimentary rocks of Tertiary age. By far the most predominant rock type is mudstone, either crushed, jointed or banded with thin layers of sandstone. There are some diapirs containing large blocks of Eocene

bentonites in the Waingake region. The high ridges which constitute the west and south boundaries of the catchment have been mapped as massive sandstone on the NZLRI, but as banded sandstone by Francis *et al.* (1989). They were confirmed as the latter by this author. East of the western margin of the catchment lies a belt of alternating beds of sandstone and mudstone interbedded with thick-bedded sandstone and tuffaceous sandstone. Small areas of light-coloured, fine-grained, calcareous rocks occur in small areas. Along the levees and terraces of the river and its tributaries is Holocene alluvium.

A field survey of lithologies and dip slopes was carried out on Emerald Hills station for familiarisation and to confirm the work of Francis *et al.* (1989). Surface lithologies are also included in the inventory on the GDC soil and water conservation farm plan for Emerald Hills maps, at a scale of 1:10,000. The field mapping on the farm plan is based on any available outcrops or exposures and on the overall "look" of the land. The difference that the type of mapping has on the interpretation of lithology is shown in Figure 3.2. Short range changes in the state of the mudstone, overlooked by geological mapping, are delineated on the farm plan.

The Te Arai syncline trending NNE-SSW is clearly obvious within a band of crushed mudstone east of the Te Arai River. The jointed mudstone to the east of the syncline is tilted up towards the east (the Rerepe anticline) (Figure 3.3). West of the syncline banded sandstone and mudstone is tilted upwards towards the Waingake anticline, Figure 3.4. Faults were noted in bands of crushed mudstone also to the west of the syncline (Figure 3.5).

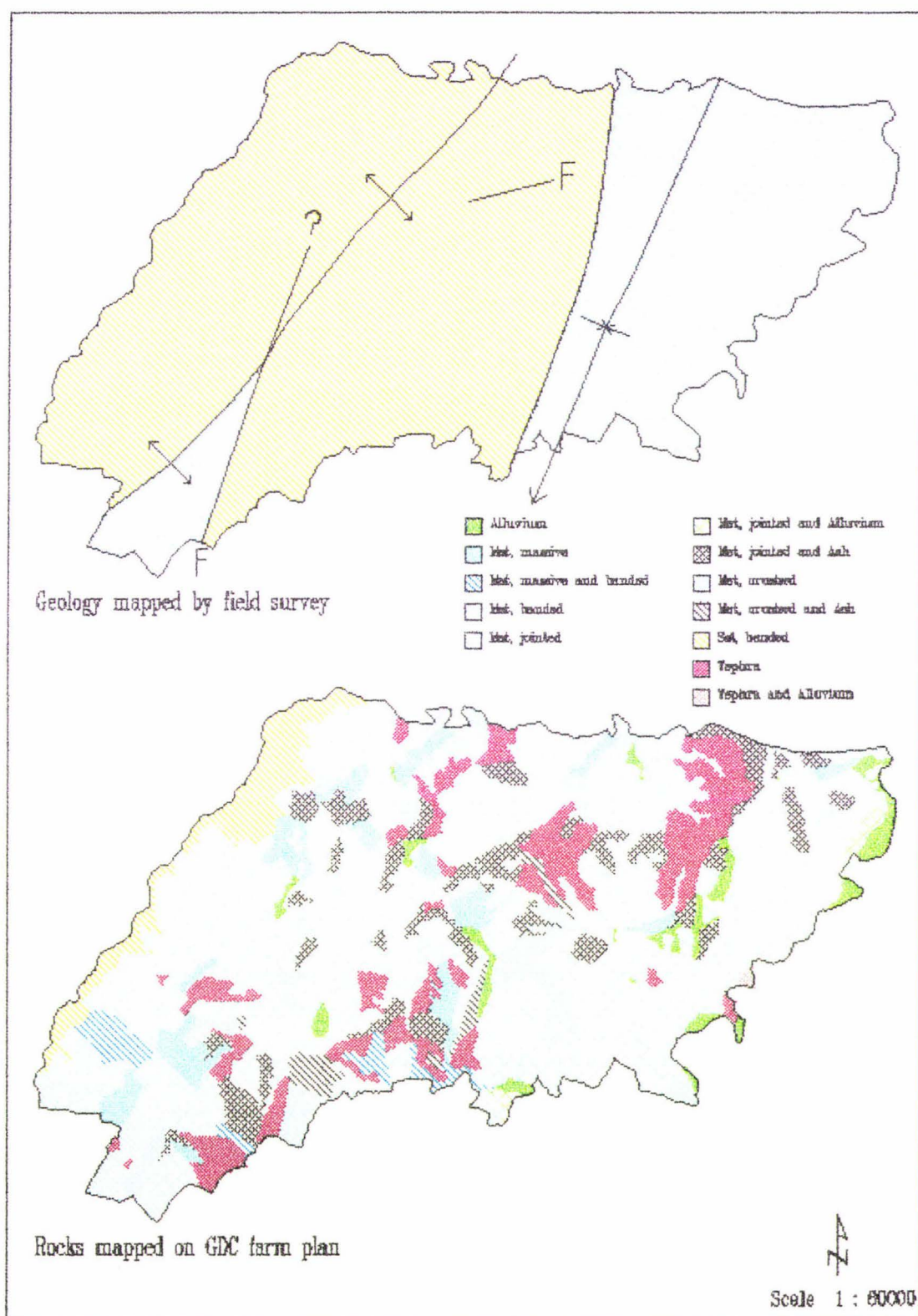


Figure 3.2 The geology of Emerald Hills station mapped from field survey compared with the lithology information available on the farm plan.



Figure 3.3 The Te Arai syncline in crushed mudstone with jointed mudstone on the right tilted up towards the east



Figure 3.4 To the west of the Te Arai syncline the banded mudstone and sandstone is tilted up towards the west



Figure 3.5 Faults are observed in bands of crushed mudstone

3.2.4 Tephra cover in the Te Arai River catchment

Although originally tephra from the Taupo and Okataina Volcanic Centres were deposited over the entire region, they have been removed or reworked by wind and rain erosion. The Taupo, Waimihia, Rotoma, Waiohau, Mangaoni and Rotoehu tephra were deposited in the region, Table 3.1. In the region, the Taupo, Waimihia, Rotoma and Waiohau are the soil forming tephra which occur within the top 45cm of the soil surface. The tephra, buried paleosols and the soils derived from these are discussed by Pullar *et al.*, (1973). Taupo ash and pumice or Waimihia formation are the most likely soil forming parent material which would result in yellow brown pumice and yellow brown loam respectively. A study carried out by Veld and De Graaf (1989) recognised

two rhyolitic ash layers on Emerald Hills and a neighbouring station believed to be from the Taupo Volcanic Zone . They identified them as the Taupo pumice which was found overlying the Waiohau ash or more often deposited on colluvium or bedrock.

<u>Tephra</u>		
<u>Tephra</u>	<u>Source</u>	<u>Date</u>
Taupo ashes + pumice	Taupo Volc. Centre	1,800 B.P
Waimihia formation	" " "	3,400 "
Rotoma ash	Okataina Volc. Centre	7,300 "
Waiohau ash	" " "	11,200 "
Mangaoni lapilli	" " "	30,000 "
Rotoehu ash	" " "	>41,000 "

Figure 3.1 Tephra deposited in the Gisborne Region, from Pullar (1973).

This study found that three tephras are recognisable on Emerald Hills station. Taupo fine to coarse ash and pumice of up to 15mm in diameter occurs mixed in the top soil; dark orangey, brown Waimihia lapilli underlies the topsoil and overlies colluvium, weathered bedrock or the light yellow cream Waiohau ash deposit (Figure 3.6). These deposits do not occur in a consistent manner.

On the higher narrower ridges to the west of the farm, exposed to the prevailing south-westerly winds there is a little Taupo ash and pumice mixed in the top soil and in many places no tephra at all. Exposures show small pockets of Waimihia beneath the top soil and overlying weathered bedrock. This is a result of infilling of small indentations in the microtopography at the time of the air fall. On the eastern shoulders of these ridges the Waimihia lapilli is found to be more extensive in cover although not consistent in depth or occurrence. The depth of this deposit may be due to overthickening by erosion from the ridges.

On broader ridges of lower elevation to the east of the farm all three tephras may still be found. On the broadest of these ridges, 10-20cm of Ah horizon contains Taupo ash and pumice overlying 10-30cm of Waimihia lapilli. Between the Waimihia lapilli and the weathered bedrock (usually mudstone) there may be up to 50cm of light yellow/brown to white tephric material. It was thought to be the Waiohau tephra from

previous descriptions of field inspections. Ferromagnesian mineralogy and electron microprobe analyses indicated that this is Waiohau ash, although the presence of a small amount of cummingtonite in some of the samples analysed suggested that there is a mixed tephra of Waiohau and Rotoma (Appendix). There is no distinct evidence of the Rotoma tephra. It is described as a thin deposit in Gisborne by Vucetich and Pullar (1964), with a sharp boundary between it and the underlying Waiohau buried soil. Possibly, the Rotoma is present in small amounts which cannot be visually distinguished from the Waiohau ash. Erosional processes following the deposition of the Waiohau may have removed any developing soil so that the Rotoma was deposited onto the Waiohau, and intermixed by pedogenic processes, or it was stripped from the landscape by erosional processes during the 4,000 yrs after its deposit and before the Waimihia airfall.

On the ridges shoulders there is often a layer of colluvium, of varying thickness, beneath the Waimihia lapilli and above the Waiohau ash (Figure 3.6). This material has been redeposited from upslope. Once again, this indicates that there was a period of slope instability sometime between 11,200 and 3,400 yrs. B.P.

Further down the slopes of broad ridges the tephras thin and in most places the Waiohau, or the Waiohau and Waimihia, are not present. There are some places on the shoulders where pockets of Waimihia or Waiohau occur directly beneath the Ah horizon. On less broad ridges the tephras are also thinner and often only the Taupo, or the Taupo and Waimihia, are present.

Between the ridges the landscape is deeply incised by drainage channels. Associated slips and earthflows have cut into the slopes to within metres of the ridges. In these areas an occasional pocket of Waimihia can be found but normally the only tephric evidence is the Taupo pumice mixed in the Ah horizon. On these slopes the Ah horizon is very thin, or missing in sites of recent erosion.

The most revealing exposures on Emerald Hills station were found on the shoulders of stable ridges not exposed to the strong south-westerlies. The following sequence was found to be common in these sites:

<i>Ah/Taupo pumice</i>	<i>10-20 cm</i>
<i>Waimihia lapilli</i>	<i>10-30 cm</i>
<i>Waiohau ash</i>	<i>10-30 cm</i>
<i>Cw (bedrock/colluvium)</i>	

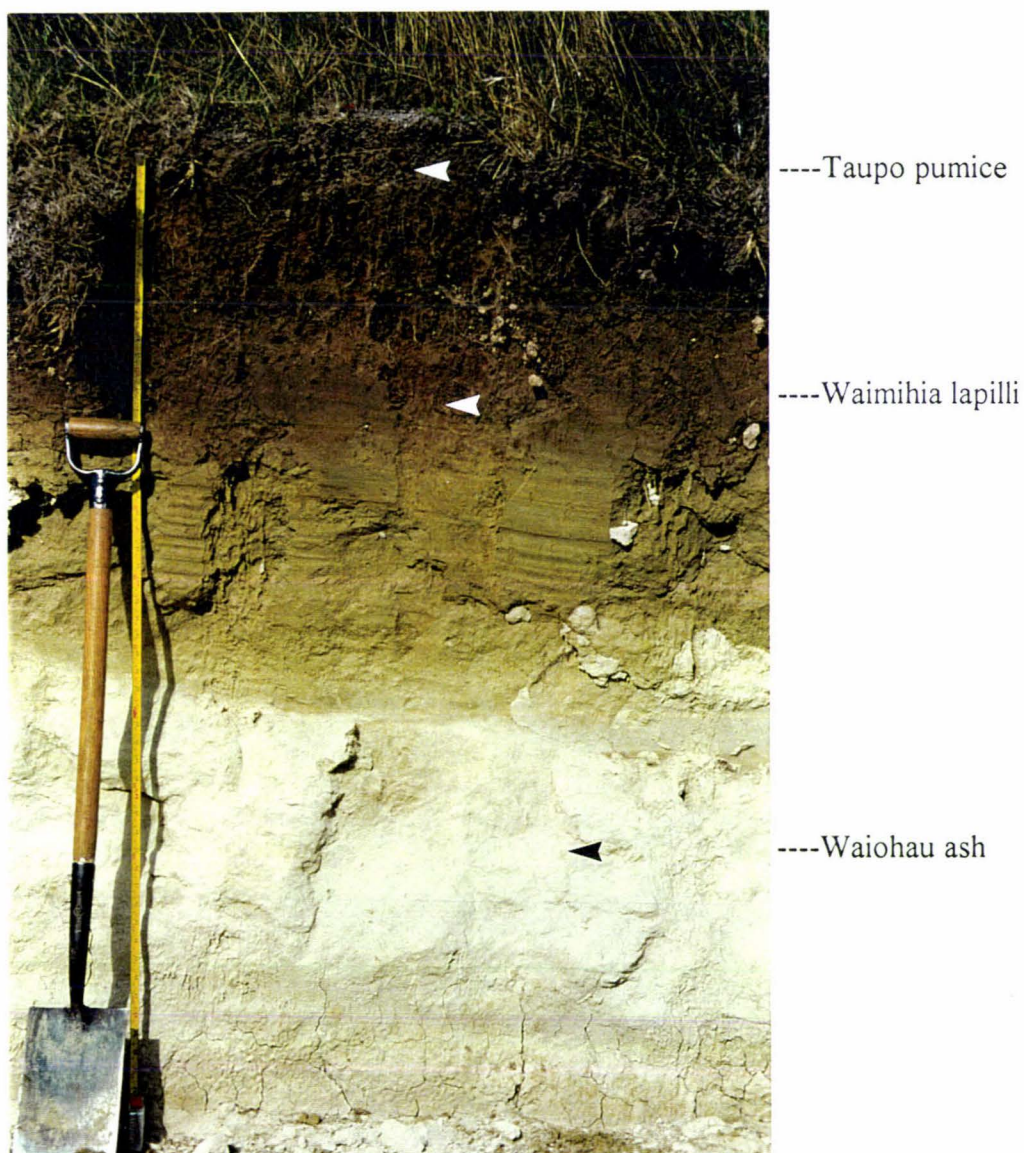


Figure 3.6

Three tephrae are found on the broader ridges and shoulders. The Waiohau ash overlying Mudstone indicates that no soil parent material in the area is older than 11,200 years. The colluvium between the Waiohau and the Waimihia infers the instability of that period.

On the 2,900ha property there are few areas where the tephras are preserved in their true sequence. A field survey revealed that all three tephras are found in only a few stable sites on the broader parts of the ridges delineated in Figure 3.7. Large areas mapped as Mj / Kt or Kt / Mj (jointed mudstone and ash) on the farm plan, are usually the more stable slopes where Taupo pumice occurs mixed in the Ah horizon.

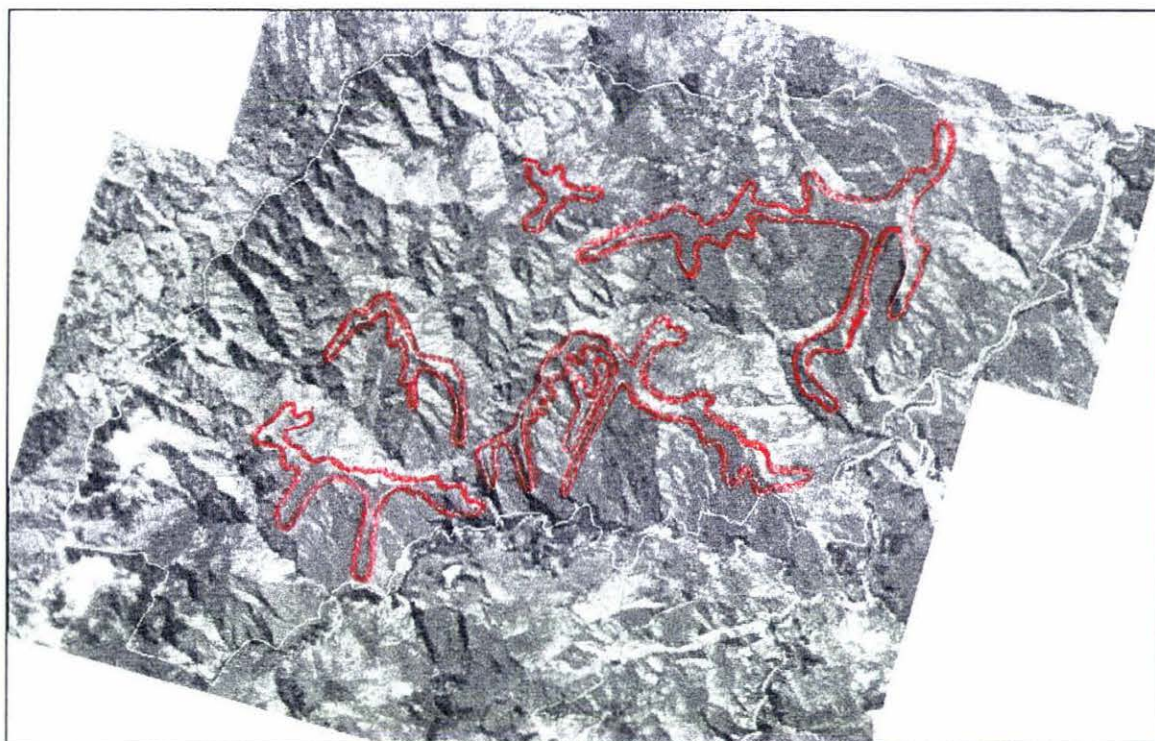


Figure 3.7 Areas on Emerald Hills station where all three tephras may be found.

3.2.5 Soils in the Te Arai River catchment

The NZLRI worksheets have soil information based on the General Survey of Soils of the North Island (N.Z. Soil Bureau, 1954) which was mapped at 1:250,000 scale. The soils are described as:

Manawatu silt loams along the river flats of the Te Arai River, Mahoenui silt loams on the mudstone slopes to the west of the river with Hangaroa sandy loam interspersed in parts (presumably where the mudstones are interbedded with sandstones), and Wharerata sandy loams on the steep banded sandstones of the western boundary ridge. To the east of the river are Turakina silt loams, Pakarae sandy loams and Wharerata and Waihua sandy loams on the western and southern boundary ridges.

A good description of the soils of the Gisborne Plains which includes the flood plains of the Te Arai River mapped at 1:15,840 was presented by Pullar (1962). In contrast to the NZLRI legend he established local soil series and mapped the Te Arai River flood plain soils as Matawhero and Waihirere silt loams with Makauri clay loam occurring in subsidiary drainage valleys.

Gisborne District Council soil and water conservation farm plans do not include soils information because they are not considered as important in their relationship to land use and land stability as the underlying rock types.

3.3 CLIMATE

The climate of the Gisborne region is classed as mild, with a large number of sunshine hours and low mean wind speed. Its position at the easternmost tip of the North Island often results in differing weather conditions from those current elsewhere. Meteorological conditions over the ocean to the east of New Zealand sometimes affect the Gisborne region alone.

Temperatures of the area are mild. At elevations less than 500m the annual range of mean temperatures lies between 7°C and 20°C; although temperatures greater than 24°C can occur on average for 65 days per year and exceed 30°C on six days, during foehn winds. At higher altitudes temperature variation is greater and there is more likelihood of frost in winter.

The distribution of rainfall in the region is influenced by the physiography. The Poverty Bay flats and their extensions are protected by adjacent hills and receive a lower rainfall than the hill country where rainfall increases from south to north and from east to west. Rainfall isohyets (New Zealand Met. Service, 1973) show coastal yearly normals are about 1,000mm compared with 1,400mm at Waerenga-O-Kuri (314m a.s.l.) to the north of the catchment, 1,800mm at Parikanapa (708m a.s.l.) on the western boundary, and 1,400mm at Waingake (60m a.s.l.) located in the centre of the catchment. For any one month the variability of rainfall from year to year is high compared with most parts of New Zealand and this is most pronounced from

December to April. This variability of rainfall combined with the drying effects of the northerly winds leads to frequent moisture deficiency for plant growth not only in the drier lowlands but also on the eroded hills where topsoil is thin.

Two extremes of rainfall occurrence are common in the east coast. Dry periods in the warmest part of the year sometimes cause a very serious reduction in the amount of pasture available for stock. The other extreme is the flood-producing rainfalls of which there are two types. First, there are the short period high intensity storms usually associated with intense cold front conditions. These storms produce local centres of torrential rain affecting relatively narrow belts in their path resulting in flood conditions in only one or two watersheds. Secondly, there is the more frequent occurrence of a generally high rainfall over a much larger area. This situation exists under cyclonic conditions when the centre of low pressure is situated to the east, north-east or north of the area (refer to section 2.9). When the depression moves slowly or remains stationary the continuous rain saturates the catchment resulting in very high run-off figures.

3.4 EROSION IN THE TE ARAI RIVER CATCHMENT

Throughout the catchment the physiography reflects historic erosional processes. Large areas have been altered by progressive earthflows, Figure 3.8. Gully erosion is evident along drainage channels and is serious in some places especially in the crush zones associated with faults and the syncline. Poplar and willow plantings, and debris dams protected some, but not all, gullies during Cyclone Bola, Figure 3.9. Stream bank erosion occurs along the Te Arai River and its 3 major tributaries, the Waimata, Kauwaewaka and Waingake Streams. Where these erosional processes remove the toes of slopes, slumping often occurs. The erosion form most obvious in the catchment is the soil slip and sheet erosion induced by Cyclone Bola in 1988, Figure 3.10.



Figure 3.8 Earthflow erosion on Emerald Hills station



Figure 3.9 Gully infilling following Cyclone Bola



Figure 3.10 Soil slip erosion following Cyclone Bola

Slip scars were estimated to be approximately 5% of the land area (C.M. Trotter, Landcare Research, Palmerston North. *pers com.*). The erosion inflicted by Cyclone Bola appeared to be restricted to pasture land with little evidence of disturbance in the bush reserve or pine blocks, except for deeply incised gullies.

That the catchment has undergone considerable erosion since about 11,000 years ago is evident by the lack of Ohakean terraces along the river and gravels and by the absence of tephra known to have been deposited in the area since that time. A layer of gravels exposed in a high bank of the Te Arai River bank about 30m above the present river level indicates the level of the valley floor during the Ohakean. The gravels are presumed to be of Ohakean age because of the overlying Waiohau tephra.

CHAPTER IV

DATA COLLECTION

4.1 INTRODUCTION

An objective of the project was to investigate the availability of existing suitable data and to utilize this data wherever possible. Thematic layers of information were collected, or developed, and stored as coverages in the vector structured GIS database of PC ARC/INFO v3.4D.

This chapter will begin by discussing how the information for this research was collected, including field surveys and remotely sensed data. Next, a section will describe the processing of the data collected in preparation for inclusion in the GIS database. This ranges from the construction of a digital elevation (DEM) from which the topographic variables; slope angle and slope aspect are derived, to the geometric co-alignment of all layers of information.

4.2 EXISTING DATA SETS

The New Zealand Land Resource Inventory data pertaining to the catchment was purchased from the Landcare Research in digital format. It included information relating to rock type, soil, slope angle, erosion type and severity, vegetation and a land use capability assessment published originally at a scale of 1:63,360 (1 inch to 1 mile). This information was obtained on diskette and loaded directly into the ARC/INFO database. The data was coordinated to the latitude and longitude geometric system and it was necessary to transform it to the New Zealand Metric Grid system using a transformation program purchased from the Department of Survey and Land Information (DOSLI), Wellington.

Land resource information was also available at a larger scale (1:10,000) for Emerald Hills station in the form of a Gisborne District Council soil and water conservation farm plan. This resource inventory was prepared by soil conservators from the District

Council as part of a comprehensive conservation plan for the farm. Areas with consistent resource characteristics are delineated on aerial photographs along with a description of those characteristics. This information is denoted in a consistent manner with the NZLRI. The information from the farm plan for Emerald Hills station was collated into the database by digitizing the resource inventory boundaries, developing a coverage, then typing the relational information of LUC, rock type, slope angle, erosion types and degree and vegetation, into the associated database table.

4.3 FIELD SURVEYS

The distribution of tephra on Emerald Hills station was mapped by field investigation and delineation on aerial photographs. During this field investigation the areas mapped on the farm plan as having a tephra cover were investigated. The extent of the tephra cover was noted and the slope angle of the land mapped within those LUC units containing tephra was measured by abney level. Erosion on the farm was inspected and verified with that evident on the farm plan or aerial photographs. Sample areas of soil slip were inspected more closely for confirming the accuracy of the image classification.

A survey of dip slopes, geologic features and lithologies on the station enabled the confirmation of the geology of Emerald Hills station as mapped by previous workers in the Te Arai catchment.

4.4 TOPOGRAPHIC DATA

Digital 20 metre contour information for the catchment was purchased from DOSLI. To obtain slope and aspect information a digital elevation model was created by a triangulated irregular network model (TIN) using the digital contour information. The development of a TIN for the entire catchment was beyond the memory capability of the 486 PC computer being used for this project. Therefore, a TIN was created for Emerald Hills station. To reduce the size of the resultant TIN and ARC/INFO coverages of slope and aspect classes, weed tolerances for vertices along the contour and z (altitude) values were set to 40m and 20m respectively. A proximal tolerance of 20m was also stipulated for triangle labels (centres). The TIN was made up of 43,026

triangles and comprised 2mb. Slope angle and slope aspect are derived from a TIN coverage by the ARC/INFO, 'TIN to polygon', conversion facility. In the process of converting each triangle to a polygon the maximum rate of change in z values across the polygons is calculated (as percent or degrees). Also, the compass direction of the maximum rate of descent across the polygon is calculated and expressed in degrees from 0 to 360. Triangles having a percent-slope of less than 1, or a degree-slope of less than 34, are considered to be flat and, having no aspect, are given an aspect value of -1. Lookup tables are used during the 'TIN to polygon' conversion to group the slopes and aspects into classes. The slope angle values were grouped into slope angle classes of 5 degree intervals (0-5, 5-10..... >40 degrees). Slope aspects were grouped into the eight octants normally used in aspect representation (N, NE, E, SE, S, SW, W, NW). The slope angle (Figure 4.1) and slope aspect (Figure 4.2) coverages derived from the TIN were 3mb and 2mb respectively.

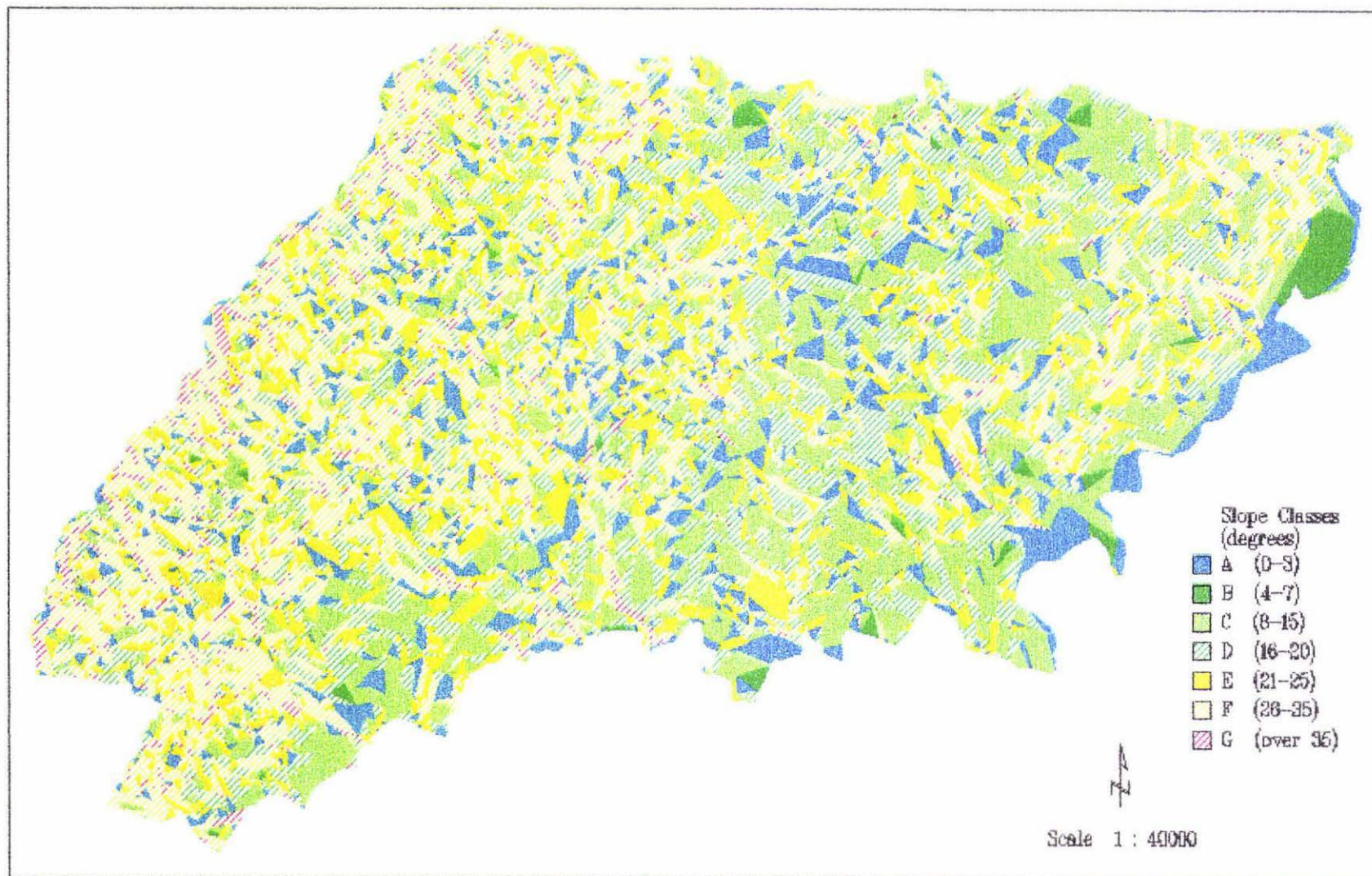


Figure 4.1 Slope angles on Emerald Hills station derived from 20m digital contour data

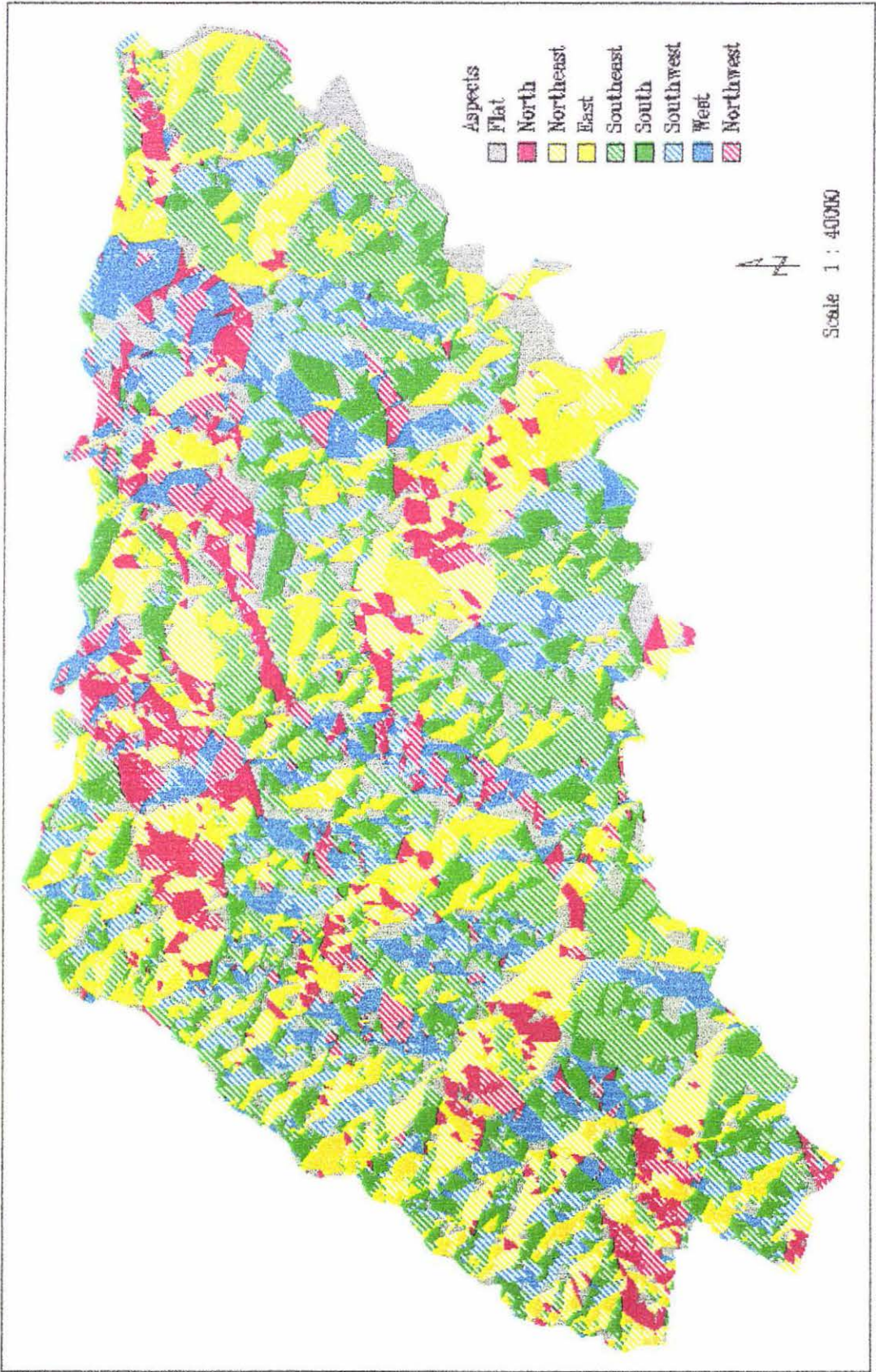


Figure 4.2 Slope aspects on Emerald Hills station derived from 20m digital contour data

4.5 REMOTELY SENSED INFORMATION

4.5.1 Satellite Imagery

A panchromatic SPOT (Système Pour l'Observation de la Terre) satellite image of the entire catchment, acquired on March 26 1988, was obtained from the Landcare Research in EPIC format, on six floppy diskettes; each subimage being 1132 rows and 1024 pixels per rows. The panchromatic sensors on the SPOT satellite consist of a high-resolution-visible (HRV) imaging system designed to operate with a 10 metre resolution over the wavelength range 0.51 to 0.73 μm .

Because of the large amount of radiometric data relating to the study area and the limited screen capabilities of the image analysis programs available, the smaller area of Emerald Hills station was selected for analysis. Using the DRAGON image analysis package data was selected from four of the diskettes and combined to provide a single image of the farm (Figure 5.1).

4.5.2 Aerial Photographs

A set of aerial photographs were purchased from Aerial Surveys Ltd, Nelson. Following a decision to use Emerald Hills station as a window in which to investigate erosion during Cyclone Bola eleven photographs were acquired in order to have full coverage of the farm. They had an endlap and sidelap of 30 percent. These black and white photographs with a format of 23 cm by 23 cm were acquired at a scale of 1:27,500 on March 27, 1988. This was within three weeks of Cyclone Bola (March 6 - 9) and therefore the soil slips were clearly identifiable on the photographs by the characteristics of tone, shape and texture (Fig 5.4a). Digital information from the aerial photographs was obtained by scanning them on a Microtek Scan Maker IISP flat bed scanner using the Adobe Photoshop (ver. 2.5) program operating in Windows. The information was stored in Tiff format which was a compatible format for importing into the DRAGON image analysis program.

To minimize the geometric inaccuracy resulting from tilt and relief displacement, as little as possible of the outer regions of each photograph was used to obtain coverage of the farm.

4.6 SPATIAL CORRELATION OF DATA FROM VARIOUS SOURCES

All data layers were registered to the New Zealand Metric Grid to facilitate overlay analysis with ground control points (GCPs) determined by digitizer from the NZMS topographic maps, 1:50,000 scale. The base GCP coverage had a positional error RMS of 2.4m, the features used for geometric registration had a horizontal map accuracy of within 15m (DOSLI). While a polynomial affine transformation was used for all geometric registrations carried out on PC ARC/INFO, it could not correct the error in the Emerald Hills station farm plan.

Because the farm plan information had been delineated on enlarged mosaiced aerial photographs there was considerable relief and processing distortion. 'Rubbersheeting' was used to correct the geometric error by aligning the farm plan with GCPs identified on the NZ metric grid. During the transformation process the features of the coverage being rubbersheeted are moved using a piecemeal transformation that preserves straight lines. It is very powerful in stretching the coverage therefore a large number of GCPs are required to ensure the accuracy of the resultant coverage.

Accuracy was ascertained by overlaying the arcs of the rubbersheeted coverage on the registered satellite image which was known to be geometrically consistent with the contour and farm boundary coverages.

The registration of the aerial and satellite imagery was carried out in IDRISI and is discussed in more detail in the next chapter.

CHAPTER V

DIGITAL IMAGE ANALYSIS

5.1 INTRODUCTION

The monitoring of the state of the natural resources under the administration of a local authority has become a statutory requirement since the enactment of the RMA, 1991.

While many studies of erosion have been carried out in New Zealand using manual methods of aerial photograph interpretation and ground survey to delineate erosional features (Trustrum and Stephens, 1978; Crozier *et al.*, 1980; Stephens *et al.*, 1981; Trustrum and De Rose, 1988), more recently, computerised image analysis (Benny and Stephens, 1985; Trotter *et al.*, 1989; Pain and Stephens, 1990; Wilde, 1992) and GIS techniques have been utilised to provide a rapid, cost-effective method of assessing the extent of degradation of the land resource.

This chapter investigates the feasibility of utilizing a simple image analysis software package and a PC computer to delineate, quickly and relatively cheaply, soil slip scars and convert that information from raster to vector data format for use in the GIS. The ability of French SPOT panchromatic satellite imagery (10m resolution) and 1:27,500 black and white aerial photography, to assist in the delineation of bare ground, is compared.

To determine the extent of soil slip erosion on the pastoral land following Cyclone Bola, to investigate the relationships between these eroded areas and other physical characteristics of the land and, to evaluate these areas for land use suitability, all the eroded areas needed to be delineated and incorporated in the ARC/INFO database. Because of the large amount of radiometric data which would need to be processed to study the entire catchment only a window, Emerald Hills station, was analyzed.

5.2 THEORY AND PREVIOUS RESEARCH

Air photograph interpretation has been an integral part of land surveys since the 1950s. Typically, erosion features have been mapped by visual interpretation and manual delineation on aerial photographs along with field survey (NWASCO, 1979; Crozier *et al.*, 1980; Phillips *et al.*, 1990; Veld and de Graf, 1990). Many of these studies have used time sequential photographs to study changes in the extent of erosion (O'Loughlin, 1969; James, 1973; Trustrum and Stephens, 1981). More recently, computerised systems have been available and these enable automated classification of surface features from remotely sensed information (Stephens, 1985).

Digital image analysis involves the storage, retrieval, interactive processing and display of digital images using computerised systems. Digital data may be obtained either directly from satellite and airborne scanners, or indirectly from aerial photographs. The latter may be accomplished by scanning the aerial photograph at a set resolution (pixel size) and recording the radiometric values of each pixel in digital format. Where the information from more than one radiometric band is used, the range of reflectance values pertaining to a feature is termed its 'spectral signature'. Many earth surface features of interest can be identified, mapped and studied on the basis of their spectral characteristics (Lillesand and Kiefer, 1987). However, this study used only black and white imagery and the pixel values describe their reflectance.

The advantage of digital image analysis over manual delineation of surface features is that, once the reflectance values of the surface features under study are identified, an automatic classification of the data can be carried out very quickly. The results of this classification are usually portrayed as a colour coded image along with a table showing the area of each representative class.

The name remote sensing was first coined in 1960 (Fischer, 1975) and referred to the observation and measurement of an object without touching it. By the late 1960s photographic methods were being used regularly and investigations using thermal infrared and microwave sensors onboard aircraft and cameras onboard satellites were being reported in the literature (Curran, 1985). From the launching of the first Earth

Resources Technology satellite (later named Landsat 1) in 1972 (Fischer *et al.* 1976) digital image data became more widely available for land remote sensing applications (Lillesand and Kiefer, 1987). In New Zealand, the EPIC software was developed in the early 1980s allowing the use of digital land resource data (McDonnell, 1986).

Digital image analysis has become a well recognised method of investigating erosion in New Zealand and elsewhere. In a storm damage assessment using digitized aerial photographs Pain and Stephens (1990) found that digital methods gave objective and rapidly obtained results. They concluded that the digital methods used in the study were superior to other objective methods of point sampling aerial photographs because of their ability to provide areal measurements as well as a map of the spatial location of landslides. Black and white aerial photographs have been extensively used because they are the most readily available at low cost and are easy to handle. Whilst these photographs allow the boundaries of erosion to be readily delineated, other types of photographs (e.g. colour and colour infrared) are especially valuable in displaying moisture, drainage, and vegetation conditions. Colour infrared film was found to be more useful for land use and erosion mapping than conventional film types such as natural colour, and black and white (Stephens *et al.* 1984). It has been used extensively for land resource mapping, for example in land use studies (Stephens *et al.* 1984) and for vegetation and erosion mapping (Birnie *et al.*, 1982). It was found to be the most suitable film type for detecting old landslide scars revegetated with pasture (Trustrum and Stephens, 1981) although, black and white aerial photography was found to be as good as multispectral data for the assessment of erosion type and extent except where only the topsoil was eroded (Cuff and Trustrum, 1983).

The use of remote sensing for mapping bare ground and vegetation was described by Benny and Stephens (1985). They found that topography had a significant effect on the spectral signature. When only surface features on sunny or flat sites were selected it was found that almost all features had unique spectral signatures. However, variation in sun angle across an image (and therefore brightness value), in particular in hill and steepland, results in overlap in the spectral ranges for different surface features making distinct definition of the features difficult.

Another problem existing with digitized aerial photographs is the spatial distortion which occurs towards the edge of the photograph due to relief displacement and radial distortion. This reduces the spatial accuracy of analyses when information derived from aerial photographs is overlaid on other geographically registered information. While most image analysis systems provide polynomial mapping facilities (*i.e.* affine, quadratic or cubic transformations) to correct geometric distortions, relief displacement can only be corrected by differential rectification (Dymond, 1991). Differential rectification of aerial (and satellite) imagery results in digital orthophotography which can be used in digital image analysis or GIS. In a GIS it can be used as an accurate base on which map overlays containing an array of pertinent information can be accurately registered. Apart from providing all the information of a photograph, digital orthophotographs also facilitate direct measurements such as lengths and areas interactively on the computer screen, profiling of the ground surface quickly and accurately, enhanced feature extraction (using image analysis systems), change detection, and efficient and accurate GIS updating (Dall, 1991).

Digital image analysis of satellite digital data has also been used in the mapping of areas of soil erosion. The earliest available satellite imagery was the Landsat MSS data with a ground resolution of 79m and four spectral bands: green (0.5-0.6 μ m), red (0.6-0.7 μ m), reflective infrared (0.7-0.8 μ m), and thermal infrared (0.8-1.1 μ m). However, some have found the MSS data has limited application potential for erosion mapping because of its insufficient resolution and its unavailability over large areas (Sauchyn and Trench, 1978; Gupta and Joshi, 1990). Landsat Thematic mapper (TM) data has been available since 1982 with higher spectral (seven bands) and spatial resolution (120m for the thermal and 30m for the rest). Another form of high resolution satellite data, SPOT with a ground resolution of 20m for the three multispectral bands and 10m for the panchromatic (black and white) band became available in 1986.

Both panchromatic (PAN) and multispectral linear array (XS) images of SPOT data were successfully utilised in the generation of an erosion map in a severely-eroded area in South China (Gao and Luk, 1989). In New Zealand, Trotter *et al.*, (1989) found the use of SPOT satellite imagery to provide quantitative data on landslide damage, on a

farm-by-farm basis, had its difficulties. This was mainly due to image mis-calculation resulting from the high degree of variation in radiance from landslides in steep hill country, exacerbated by the low sun angle at the time of image acquisition. The typical topographic variation within the area covered by one farm meant that it was necessary to classify the image as a series of small segments, essentially at the hillslope scale.

In the MacKenzie Basin, satellite imagery provided a rapid and cost effective method for quantifying the extent of land degradation, due in part to intensive grazing by rabbits (Wilde *et al.*, 1991). By ground survey they established a relationship between percentage vegetation cover and normalised vegetation index ($NVI = [IR - R / IR + R]$) of SPOT XS data. Results indicated that soil types have a strong influence on the areal pattern of degradation with areas of more than 80% cover having good moisture-holding capacity.

Digital aerial and SPOT imagery is being utilised in an ongoing study of the change in bare ground in an area of sand dunes and plains within the Manawatu coastal sand country (Wilde, 1992). NOAA-AVHRR imagery has become the prime source of remotely sensed data for monitoring land cover in the context of global change, because of its near global coverage, frequent data acquisition schedule, and its proven ability to detect land cover changes (Millington, 1991). However, its resolution (1.1km) does not assist detailed land cover mapping.

Airborne multispectral scanner data is proving to be very useful for the detection of erosional features. They provide enhanced spatial and spectral resolution data over that which may be achieved from satellite data (Agar, 1991). In New Zealand, the Bay of Plenty Regional Council has utilized airborne remote sensing to build a database of its environmental resources. A Daedalus MSS was fitted to a Gates Lear Jet to obtain imagery of 30m resolution.

5.3 DETERMINATION OF CYCLONE BOLA SOIL SLIPS

5.3.1 Cyclone Bola soil slips derived from Satellite Imagery

Initial statistics of the imagery showed that brightness values fell between 12 and 136 resulting in a dark image. This is due to the low solar illumination associated with the time of day and the season (10 am, March 26th). A linear contrast stretch image enhancement procedure was applied to the image in order to expand, uniformly, the range of pixel values to 0 - 255. The greater contrast in the image assisted subsequent visual determination of ground control points (GCPs), and brightness range setting for each land cover.

Because DRAGON's registration module had a bug at the time the registration was carried out in IDRISI. The satellite image was registered (geometrically corrected) to the NZ metric map grid, Figure 5.1, by selecting GCPs which were clearly identifiable on both the image and the NZMS 260 map series (1:50,000) from which eastings and northings were read. These GCPs were road intersections, field boundaries, stream confluences or ridge peaks as suggested suitable by Benny, 1983. IDRISI uses a linear polynomial fit and a nearest neighbour resampling method (Richards, 1986) to transform the image geometrically. The functional relationship between image X and Y, and map easting and northing is determined by a least squares regression. The transformation error for the satellite image was 3.06 pixels, 30.6m. By overlaying contour lines and by running a cursor over the registered image checking the geometric coordinates with the topographic map it was determined that the registration was very successful. An accurate transformation of an image covering this area of land was expected to be difficult when it is understood that one pixel must be selected to represent the GCP, a subjective process; that a pixel in the SPOT image represents a 10m by 10m surface area; and IDRISI uses the bottom corner of the cell for the transformation process. Minor transformation error was due to relief displacement although of much less scale than on the aerial photography because of the far greater elevation of the sensors.

The registered image was converted to the DRAGON format (using a TIFF intermediary) and then classified. Unsupervised (clustering) and supervised

(parallelepiped) classification procedures were carried out with the parallelepiped (boxcar) classification being the most successful at discriminating bare ground from other surface cover because of the ease with which the spectral range could be manipulated. The fundamental difference between these two techniques is that in the clustering process the image data is classified by aggregating the pixels into natural spectral groupings present in the image, while supervised classifications involve a training step where the analyst identifies pixels in the image which represent the features under study. A set of statistics (signatures) is then assembled which describes the spectral response pattern for each land cover that is being studied on the image; each spectral class represents one information class which can be discriminated by the classifiers. For a successful classification of the image into classes representing each land cover, the signatures of each class should not overlap each other. Representative areas (training areas) were delineated on the image for the two classes; bare ground (representing slips from Cyclone Bola) and pasture/trees.

An attempt was made to classify for trees, pasture and bare ground. However, when the image was classified for the three land cover classes the resultant image showed that trees and pasture could not be discriminated. This was due partly to the amount of shading on the image and also to the characteristics of the trees themselves. The trees that were of most interest were space planted poplars and willows which were used for conservation works in eroding areas. These had similar reflectance values to pasture. Being autumn the tree leaf colour would be subdued and it is possible the poplars were affected by rust. Also, where there were only one or two small trees occupying a pixel, which represented 10m by 10m of ground area, the pixel would record the dominant reflectance character which was pasture.

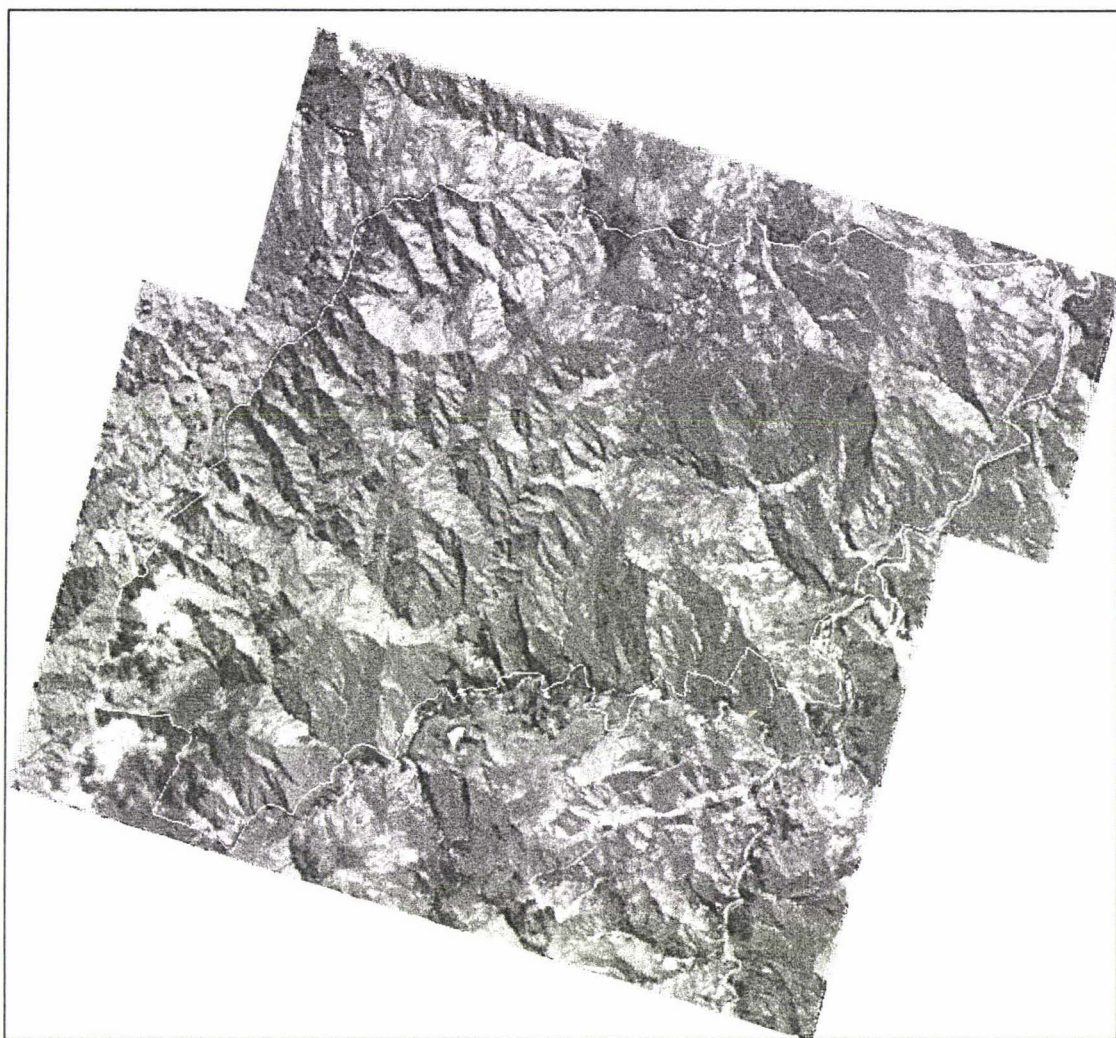


Figure 5.1 Satellite image of Emerald Hills station, registered to the NZ metric grid.

A parallelepiped classification was chosen as the minimum distance to mean and maximum likelihood methods are not suited to a single band of information. The classification process was a very simple discrimination of two spectral classes; the lighter and the darker, with the distinction being such that the classes accurately represented the surface characteristics of bare ground or vegetation.

The classification procedure involved adjusting the range of reflectance values in the feature signature file until it resulted in a distinct delineation of the land cover classes. This is often referred to as density slicing. The classified image was compared with the original image and the signature ranges adjusted until a satisfactory classification was obtained, Figures 5.2 (a) & (b).

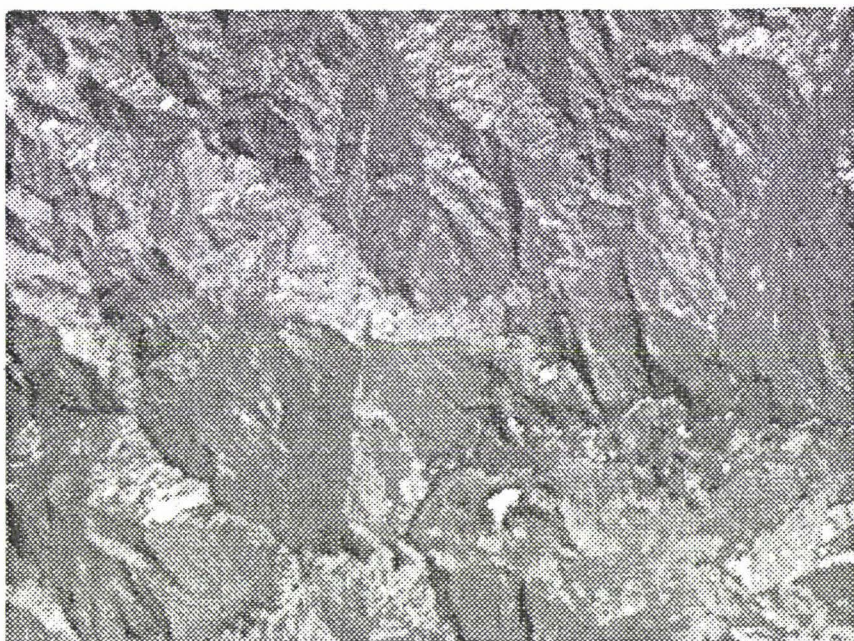


Figure 5.2(a) Sample area from satellite image

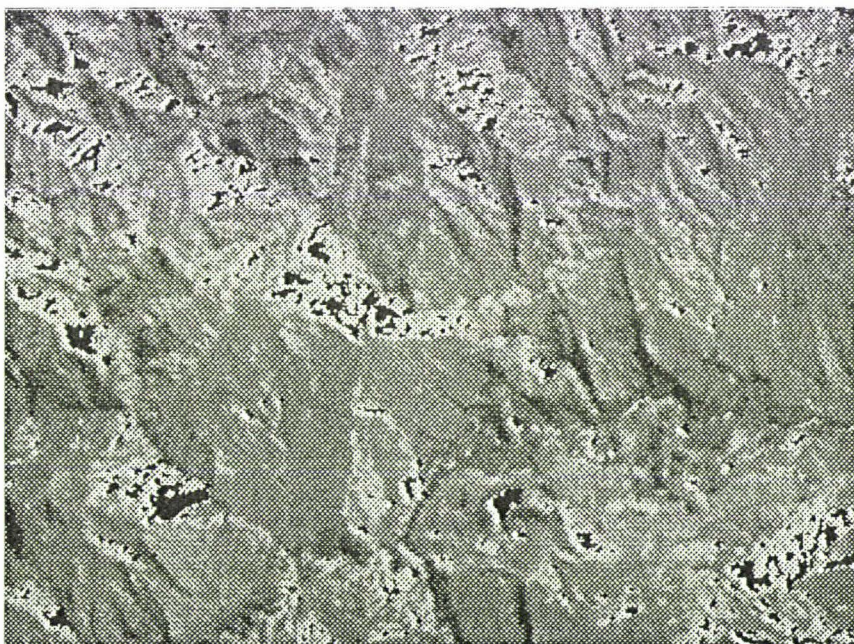


Figure 5.2(b) Satellite image (a) with areas classified as bare ground overlaid

Because of DRAGON screen limitations the satellite imagery was processed as four subimages. To retain attribute information during conversion from raster to vector data systems the images were transferred to EPPL7 (Environmental Planning and

Programming Language) in TIFF format then imported to ARC/INFO using the ARC/INFO GRIDPOLY facility.

In ARC/INFO the image was clipped to the boundary of Emerald Hills station. 4.7% of the station had been classified as bare ground. This decreased to 4.5% after editing to remove areas of river bed erosion, roads and farm tracks, Figure 5.5.

5.3.2 Cyclone Bola soil slips derived from Aerial Photography

Firstly, an area from a 1:27,500 black and white aerial photograph was scanned at 10m, 5m and 1m resolution to determine whether there was great advantage in scanning at higher resolution. The higher the resolution the greater the amount of data generated for processing and the more likely the need to subsample the imagery to accommodate the image data and screen limitations of the software.

It was expected that the higher resolution (1m) would facilitate the selection of intensity value ranges and that the classification would result in smaller slips being identified. However, there was no change in the spectral limits assigned to each class from the 5m or 1m resolution images because the spectral information was from the same source image. Nor was there any change in the percentage of bare ground classified on each of the three images, Figure 5.3. The classified features appeared smoother on the 1m resolution image but any advantage in delineating smaller slips was limited by the reflectance variation in the image.

Therefore, the classification of the aerial photographs was carried out on five photographs covering Emerald Hills station scanned at 70 dots per inch (dpi) to derive digital aerial information of the same resolution as the satellite imagery (10m), Figure 5.4(a). This would allow a comparison of the two data acquisition types.

During the scanning process the range of grey tone intensities was set at 0 - 255 therefore no further manipulation was required at this stage. Each image was registered to the topographic grid by the same process as above. However, where it

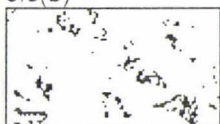
was found that the satellite image was registered quite easily and accurately, positional error was unavoidable for areas further from the centre of each photograph with the worst error occurring at high or low sites due to relief displacement. Some points on three of the images were up to 50m in error.

Each image was classified to delineate bare ground in the same manner as the satellite image, verified for accuracy of classification (Figure 5.4(b)) and exported to ARC/INFO. The coverages were clipped to the boundary of Emerald Hills station and combined to form two coverages of bare ground. 6.8% of Emerald Hills station was classified as bare ground on the aerial photographs reducing to 6.1% after the removal of areas associated with river bed erosion, roads and farm tracks, figure 5.5.

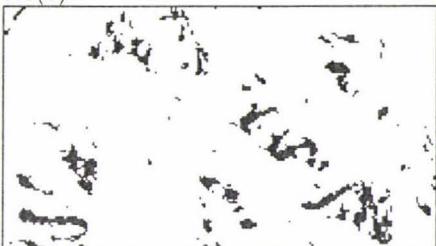
5.3(a)



5.3(b)



5.3(c)



5.3(d)

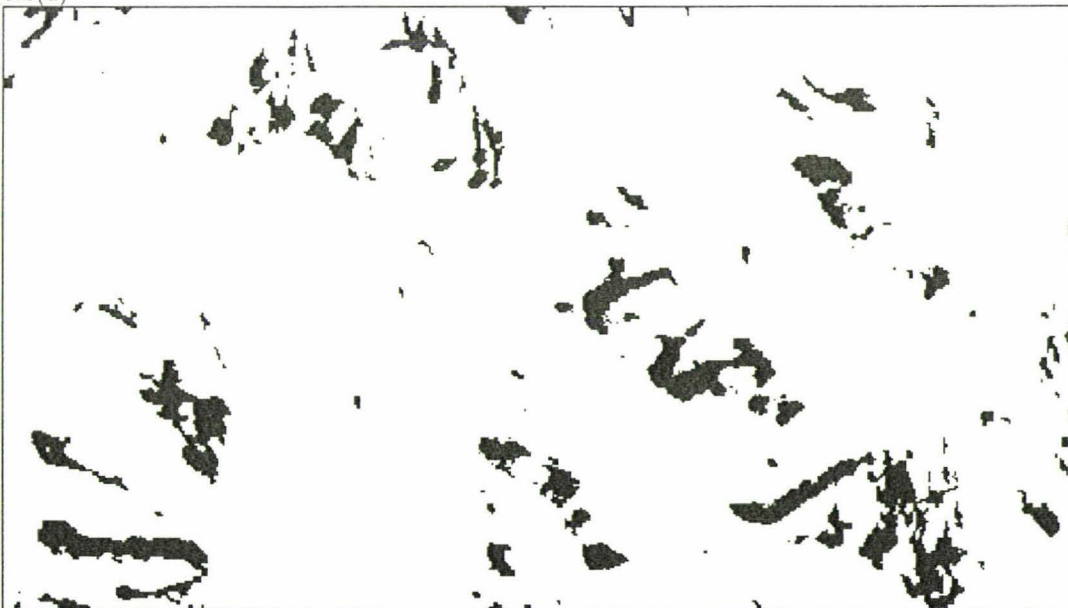


Figure 5.3 Sample area from aerial photograph (a), and the results of classification of the photograph scanned at 10m(b), 5m(c), 1m(d) resolution.



Figure 5.4(a) Sample area from aerial photograph, scanned at 10m resolution

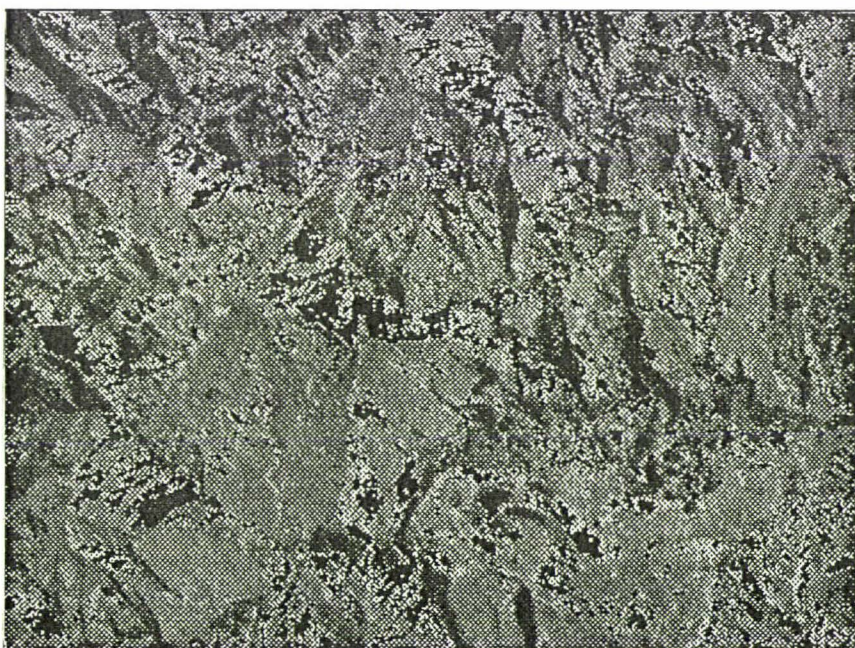


Figure 5.4(b) Aerial photograph (a) with areas classified as bare ground overlaid.

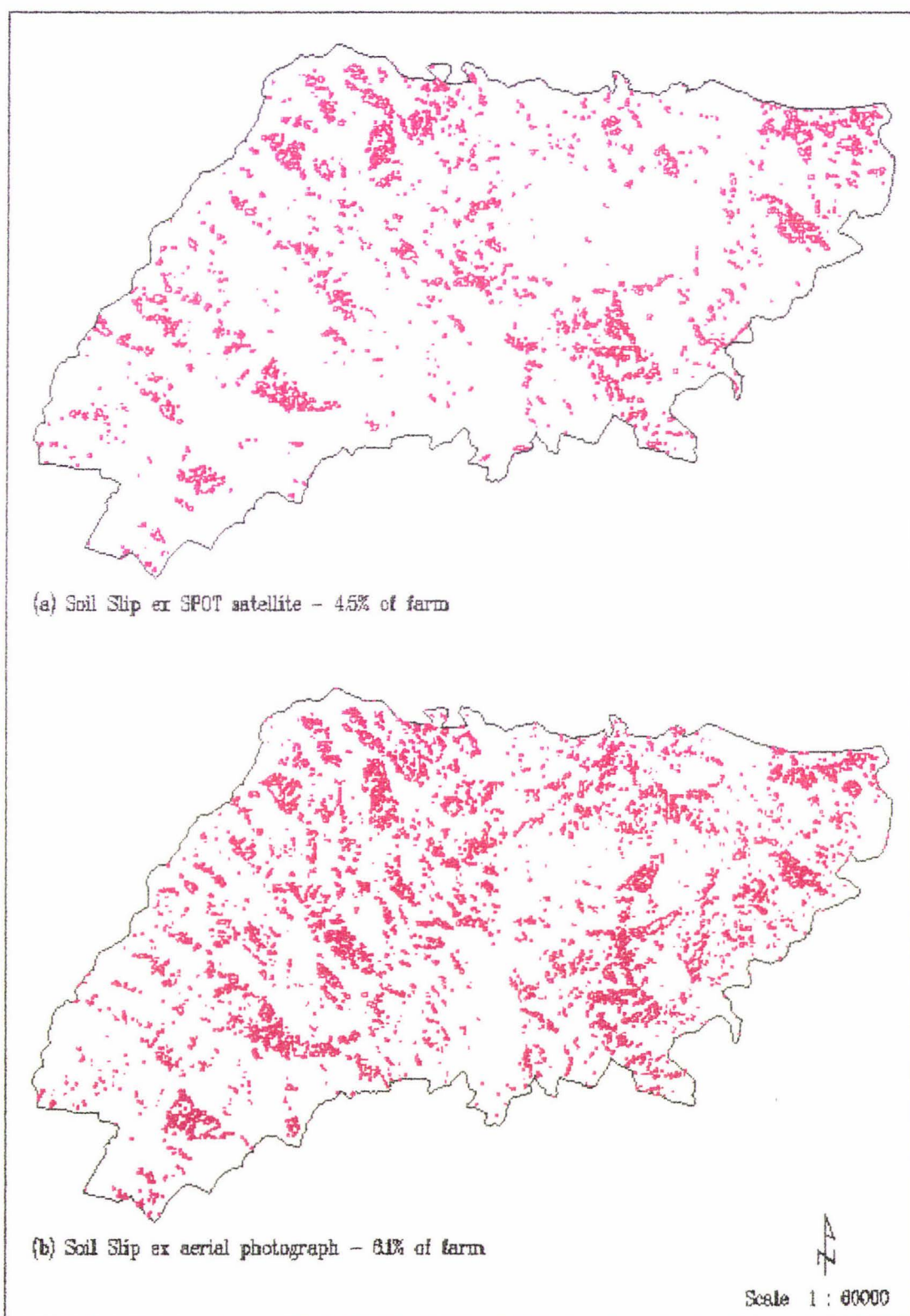


Figure 5.5 A comparison of soil slip erosion derived from (a) satellite imagery and (b) aerial photography

5.4 EVALUATION OF DIGITAL IMAGE ANALYSIS.

Several points of importance in the suitability of remotely sensed information became clear during this part of the project.

For remotely sensed information to be of value to resource managers the imagery (digital) must be able to be registered accurately to the geographic reference system being used in the GIS database. It must also be capable of providing the relevant information about the subject for which it is being used, and the derivation of this information must be within the capabilities of the computer software and hardware available and the skills of the people who are to use it.

Contact prints of areas of variable terrain are not easily registered to a geographic reference system because of the amount of relief displacement. Panchromatic imagery is adequate for the identification of bare ground, especially recently eroded, but it is not a good source for discriminating vegetation types. Colour, colour infrared and multispectral imagery has been found by others to provide better information about soil physical properties, revegetated erosion scars and vegetation type and vigour (Trustum and Stephens, 1981, Stephens *et al.*, 1984).

The scale of acquisition affects the amount of information that can be derived from the imagery. For studies of resources at the catchment or farm scale aerial photographs of scales 1:10,000 - 1:30,000 are routinely used (less than 1.5m resolution). For more detailed vegetation/bare ground mapping a scale as large as 1:1,000 may be necessary.

5.4.1 Satellite imagery

While the satellite derived information was easily and accurately registered it identified about 30% less bare ground than the aerial photography; 4.5% of the farm was identified as bare ground on the satellite imagery compared to 6.1% on the aerial photography.

The variation in reflectance values (grey tones) on the satellite image was such that it was not possible to obtain an accurate discrimination between land cover classes in a single classification of the image. There were considerable areas in the satellite image which had shadowing. There was also a large variation of reflectance values which resulted in some areas of pasture on bright north-facing slopes having similar intensity values to bare ground. This variation in intensity values is due to the affect of low sun elevation at the time of image acquisition and the degree of topographic variation (Trotter *et al.*, 1989). Elevations on the farm varied from 40 to 700 meters above sea level. In order to achieve an accurate delineation of bare ground Trotter *et al.*, (1989) found it necessary to classify the farm at the hillslope scale. This requires a reasonable level of sophistication in the equipment and expertise in the user which is often not readily available in a local authority where the degree of complication and time expenditure would be undesirable.

5.4.2 Aerial Photography

The scanned aerial photographs could not be registered with the same accuracy as the satellite imagery. Polynomial transformations (as used by IDRISI) can correct low frequency distortions, such as those introduced during scanning, but it is necessary to carry out differential rectification on digital aerial imagery to correct relief displacement (Dymond, 1991). The cost of differential rectification was beyond the resources of this project.

The images could not be combined into one after registration but had to be classified individually. This was because the intensity ranges for bare ground and vegetation were not consistent across all five images.

The same problem of variation in reflectance values was encountered in the aerial imagery (although to a lesser degree) resulting in areas of pasture on bright slopes being classified as soil slips and, many shallow soil slips as well as slips on darker slopes not being discriminated from pasture.

The orientation of the camera view on different flight paths also affected the variation in reflectance values. It took several manipulations of the signature classes to arrive at an acceptable classification for each image.

To ascertain which source of imagery provided the best information the extent of bare ground within sample areas on the aerial photographs was calculated by grid counts. It was found that this method and the classification of aerial photographs produced the closest percentage of bare ground (within 1%), with the grid count results being lower. However, closer inspection showed that the computer assisted classification process did not identify small areas of bare ground (<4m²). Field inspection revealed these to be very shallow soil slips which would therefore have a low reflectance value resulting in their miscalculation. Most of these had significantly recovered their grass cover within five years and were difficult to detect in the field. The computer assisted classification method also resulted in the exaggeration of many bare areas. This was a result of manipulation of the intensity range to include areas of bare ground that had lower pixel values (were less bright).

5.4.3 Discussion

Satellite imagery is easier to register to a topographic grid because of the larger size of the image and the distance from which the imagery is acquired. There is not the same relief displacement as encountered in lower altitude imagery where the position of features of higher relief is exaggerated outwardly from the centre (view point). Black and white aerial imagery is available as digital orthophotography (removing registration errors) which at present is expensive but, for the development of comprehensive inventories of physical resources as required under the RMA, and the full utilisation of the advantages of a GIS, geometrically correct information is essential.

Satellite imagery facilitates the expedient acquisition of information where only a regional assessment of surface features is required. However, the highest resolution satellite imagery available in N.Z. is SPOT panchromatic data with a ground resolution of 10m. For vegetation inventories multiband imagery is more appropriate which is

available as 20m SPOT XS data or 30m Landsat TM data. Therefore, satellite is at best an aid to soil conservation and a complement to aerial photography (Stephens, 1982).

Although the resolution of the two sources of information used in this study was consistent, 10m, the photography detected 30% more bare ground than the satellite image; 6.1% compared to 4.5%.

Therefore, using the inexpensive image analysis program, DRAGON, aerial photography has been found to have more potential to delineate soil slips than satellite imagery although classification of neither satellite or aerial photograph delineated all soil slips which were discernible by eye. In manipulating the intensity range to include as many areas of bare ground as possible some larger areas of bare ground were clearly exaggerated and some areas of bright pasture were mis-classified as bare ground.

The information obtained from the 1:27,500 scale black and white aerial photographs scanned at 10m resolution is adequate for the investigative purposes of this study; to delineate fresh soil slip erosion at the farm scale. It is not appropriate for identifying vegetation types. This would best be done using low altitude aerial colour infrared imagery (Stephens *et al.*, 1984).

A similar study using a system which was able to resolve the problem of intensity variation by partitioning the satellite imagery into sub-images of similar slope-angle and aspect assessed the total area of soil slips as 5.0% (C. M. Trotter, Landcare Research, Palmerston North, *pers comm.*) A ratio of 32:68 was applied to the area of soil slip to partition the slip scar from the tail-debris in a study by Trotter *et al.*, (1989). The calculation of the actual area of slip scar was used to compensate farmers for loss of future earnings foregone as a result of damage incurred during Cyclone Bola. Where productivity on the debris-tail is generally recovered within 1 to 3 years, productivity remains severely depressed over a much longer term, often of more than 20 years (Lambert *et al.*, 1984).

This study found that it was not possible to partition the slip scar from the tail debris on either satellite imagery or the 1:27,500 scale aerial photography.

CHAPTER VI

INVESTIGATING THE CHARACTERISTICS OF SOIL SLIP DISTRIBUTION USING A GEOGRAPHIC INFORMATION SYSTEM

6.1 INTRODUCTION

Statutory obligations inferred upon local councils by the Resource Management Act, 1991, create the need for prompt access to property-related information and reliable spatial data, such as details of topography, infrastructure and the state of resources.

Geographic Information Systems allow the storage of spatially-related data which can be investigated at will, as compared to classifications prepared for specific purposes. They are utilised by land use planners, resource managers and researchers who need to access spatially-referenced information on a regular basis. Storing land resource data in a GIS provides the capability to (a) easily retrieve information, (b) produce information tailored to different needs, (c) display and discover information through manipulation of large data bases, and (d) identify and assess variables for predictive models (Walsh, 1985). The ability of GIS to associate area-related attributes and integrate layers of this information makes them a valuable tool for land use planning and management. There is a range of analytical capabilities offered that facilitate resource appraisal and management.

GIS are commonly utilised throughout the world to facilitate the acquisition and storage of information relating to the present state of resources (Eyles and Newsome, 1990; Bolstad and Lillesand, 1991) and to determine the affect on a resource following a detrimental event (Trotter *et al.*, 1989). Their analytical tools assist the investigation and prediction of land degradation susceptibility (Wadge, 1988; Jayawardhana, 1990; Gupta and Joshi, 1990; Wang and Unwin, 1992) and the development of land use

scenarios based on land use suitability (Christodoulou and Nakos, 1990; Chuvieco, 1993; and Wardle *et al.*, 1993).

The usual method of investigating the distribution and characteristics of erosion has been to carry out field surveys (Dent and Young, 1981), or to measure the density of erosion events on aerial photographs. By overlaying transparent thematic maps on aerial photographs the distribution of erosion per each class within each thematic layer was measured. This is, essentially, the same process that is used in the GIS. Thematic layers are retrieved from the database and queried individually or in combination with information from other layers. Financial constraints often limit the amount of field surveying which can be carried out. GIS allows the manipulation of existing data layers for the retrieval of information specific to the study and, enables the investigation of larger samples; in this case the entire area of Emerald Hills station.

In the East Coast region the major physical limitation which determines sustainable land use is soil erosion. According to Crozier *et al.*, (1982) the rate of erosion in New Zealand is a function of the combined effects of relief, rainfall and uplift. Others include the factors of lithology (Claridge, 1960; Gage and Black, 1979) and land use (O'Loughlin and Pearce, 1976; Hicks, 1989; Phillips *et al.*, 1990).

When viewing aerial photographs of the Te Arai River catchment there appeared to be more soil slip erosion on north- and east-facing slopes. In this chapter the distribution of soil slip following Cyclone Bola in relation to aspect, and other relevant site factors, is investigated. This is accomplished using the analytical capabilities of the GIS, PC ARC/INFO, and the soil slip information derived from image analysis (chapter five).

6.2 PREVIOUS WORK

6.2.1 Aspect

Several previous studies have shown a relationship between slope aspect and the distribution of soil slip erosion. A regional survey of mass movement in the Wairarapa hill country during the very wet winter of 1977 by Crozier *et al.* (1980) found aspect was the most influential factor involved in the location of slips. Northerly,

northwesterly, northeasterly and easterly aspects sustained far more soil slip than other aspects, with the most unstable location being the upper segment of slopes facing north. The higher incidence of slipping on the upper slopes of northerly aspects was attributed (although inconclusively) to the availability of regolith which is less stable than slope material that has been subject to previous slipping. Much of the regolith on shady slopes and the lower portions of sunny slopes had been removed by mass movement in the past. Following Cyclone Bola, 1988, the majority of soil slips in a study on Arai-Matawai and Emerald Hills stations, in the Te Arai catchment, were found to have occurred on slopes with a northerly, northeasterly or a easterly aspect (Veld and de Graaf, 1990). This was explained by them as due to the direction from which the cyclone struck the area. They also proposed that north-facing slopes were more susceptible to erosion from a summer storm because they are steeper and, intercepting more sunlight, are much dryer than slopes on other aspects. Poorer pasture and less organic material in the soil results in less infiltration of rain water, greater surface runoff and surface erosion. A study in the Raukumara Peninsula following two storm events also found most slips occurred in the north- and east-facing octants and on upper slopes (Phillips, 1988).

However, aspect had no effect on the distribution of soil slips in the Pohangina district following a prolonged wet winter and spring in 1992 (Lough, 1993). The erosion followed a long wet period as did the erosion in the Wairarapa, 1977 (Crozier *et al.*, 1980) but, the lithology of the Pohangina area is different from the areas of the other studies quoted here. The unconsolidated Pleistocene marine sands are more likely to sustain erosion during heavy rain than the more indurated lithologies of the other study areas. This proneness of the lithology to soil slip may have been a greater factor than slope aspect.

6.2.2 Slope Angle

The incidence of slipping in any one area will increase with slope angle (Eyles *et al.*, 1978). This was found to be so in the steep land hillslopes in Taranaki following two high rainfall events (De Rose *et al.*, 1993). Increasing slope angle caused differences in

regolith depth with the depth of regolith being inversely related to slope angle regardless of vegetation cover.

There is a critical slope angle below which landslips will not occur under a given set of hydrological and inherent slope conditions (such as lithology). This angle was approximately 24° for the 1977 mass movement episodes on mudstone in the Pakaraka catchment, Wairarapa (Crozier *et al.*, 1980). All post-deforestation landslides in a study area on mudstone hillslopes in Taranaki have occurred on slopes with a mean slope angle above 28 degrees (De Rose *et al.*, 1993). On hill country of unconsolidated sand in the Pohangina district the critical slope angle for soil slip was 15° (Lough, 1993) with an increase in the average percentage of erosion with slope angle to the 25° - 29° slope class.

In the East Coast region following two large storms, 1980 and 1982, most landslides occurred on steep slopes (35°) (Phillips, 1988) but, following Cyclone Bola, 1989, slopes of between 20° and 32° experienced the most slipping (Veld and de Graaf, 1990). This difference may be attributable to the difference in the lithology of the two study sites. The first study was carried out on Mid Cretaceous to Paleocene sandstones and alternating sandstone/mudstone sequences whereas the lithology of the second study area contained a larger proportion of Paleocene to Late Miocene mudstone.

On Wairarapa hillslopes (mean slope angle 28°) nearly 56% of the area of remnant forest soils have been eroded since deforestation (Trustrum *et al.*, 1984), and on Wairoa hillslopes steeper than 30° landslide erosion has affected 80% of the hillslope since forest removal (Trustrum and Blaschke, 1992). The depletion of regolith from steep land hillsides in Taranaki was found to be a function of slope angle with losses occurring on hillslopes over 28° ; the greatest losses occurred on hillslopes over 32° . The incidence of soil slip on the Wairarapa hill country in 1977 could not, however, be explained in terms of slope angle alone (Crozier *et al.*, 1980).

Soil slips have been found to occur in preferential positions within a slope. In many cases the slips are eroding the edge of a cap of undisturbed material which mantles

ridge crests and hilltops (Crozier *et al.*, 1980). Slips most frequently occur within swales preferentially removing the deepest regolith from the hillslopes. They rarely occur on spurs but may occur along the side of spurs reducing the spurs width (De Rose *et al.*, 1993). Slips occurred mainly on the upper part of north-facing slopes (Veld and de Graaf, 1990).

6.2.3 Lithology

The relationships between lithology and slope stability, erosional behaviour and land use capability have long been recognised in the East Coast area. The severe instability of certain lithologies following forest clearance for pasture development was referred to by Ongley and MacPherson (1928). Similar problems were referred to by Grange and Gibbs (1948). The importance of lithologic control in the distribution of the most severely eroding areas was stressed by Hamilton and Kelman (1952) and Claridge (1960). Rock types most susceptible to mass failure contain high proportions of the swelling clay, montmorillonite (Claridge, 1960). The rock types and soils of the Gisborne - East Cape region were grouped in order of increasing severity of erosion by O'Byrne (1965). Following a land use capability survey he described the rocks, soil and erosion type and severity in each Class differentiating erosion into that within the soil mantle and weathered rock (slip and sheet) and that within the bedrock (earthflow, slump and gully). He concluded that the physical properties and chemical composition of the rocks have more influence on the processes of erosion than environmental factors. Soil erosion is dominant over rock erosion in limestone, consolidated sandstones, massive mudstone and basalt. Bedrock erosion becomes more important in the unconsolidated sandstone, close-jointed mudstone, shattered Cretaceous shales, argillites and erodible greywackes. Bentonitic mudstone and crushed mudstone have the most severe bedrock erosion (earthflow, slump and gully).

A terrain-stability classification, based on lithologic contrasts for the upper Waipaoa and Mangatu catchments, was developed by Gage and Black (1979). They examined the montmorillonite content of Late Cretaceous and Early Tertiary sediments. The greater the montmorillonite content is within these sediments the more prone they are

to slope failure. Gage and Black (1979) also refer to the effect that a layer of tephric material has on the landscape.

Most geological mapping prior to the NZLRI (the major exception being O'Byrne, 1967) used time-stratigraphic units as descriptors. These did not specify rock type which is one of the factors used in determining the limitations and potentials of land. Therefore, a rocktype classification was developed for use in the NZLRI land use capability assessment. The rocks of the North Island were classified into 31 groups with similar erosion susceptibility and characteristics (Crippen and Eyles, 1985).

6.3 METHODOLOGY

The individual layers of slope angle, slope aspect, and rock type (chapter four) were intersected by the layer containing the soil slip information derived from image analysis (chapter five). The intersection procedure results in a layer containing only the areas which are shared by both the original layers (Figure 6.1).

Multifactor layers were also produced by combining the layers of slope and aspect; slope and rock type; and, rock type and aspect before their intersection with the soil slip layer (Figure 6.2). The database table of the resultant layer contains information obtained from the database tables of both of the original layers.

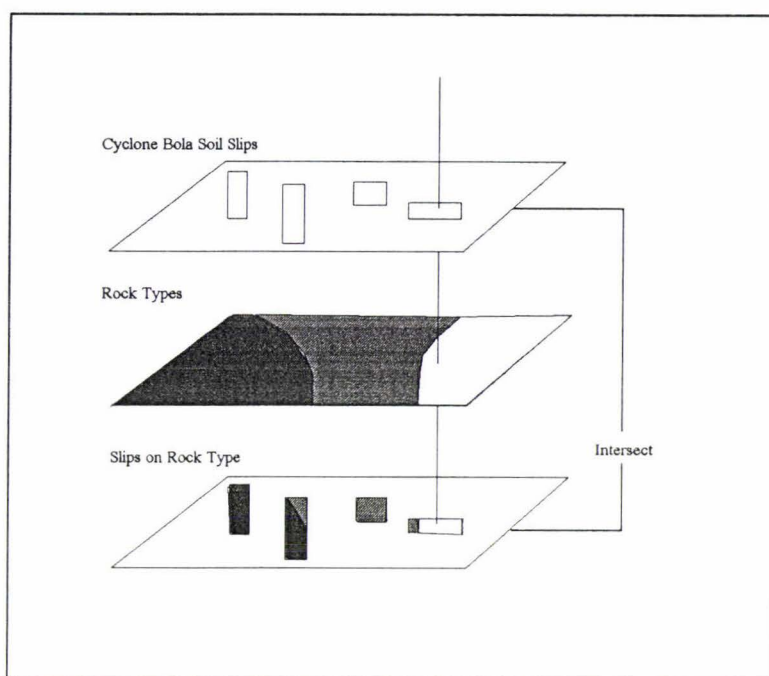


Figure 6.1 Overlay ('intersection') procedures to provide soil slip per landscape feature information.

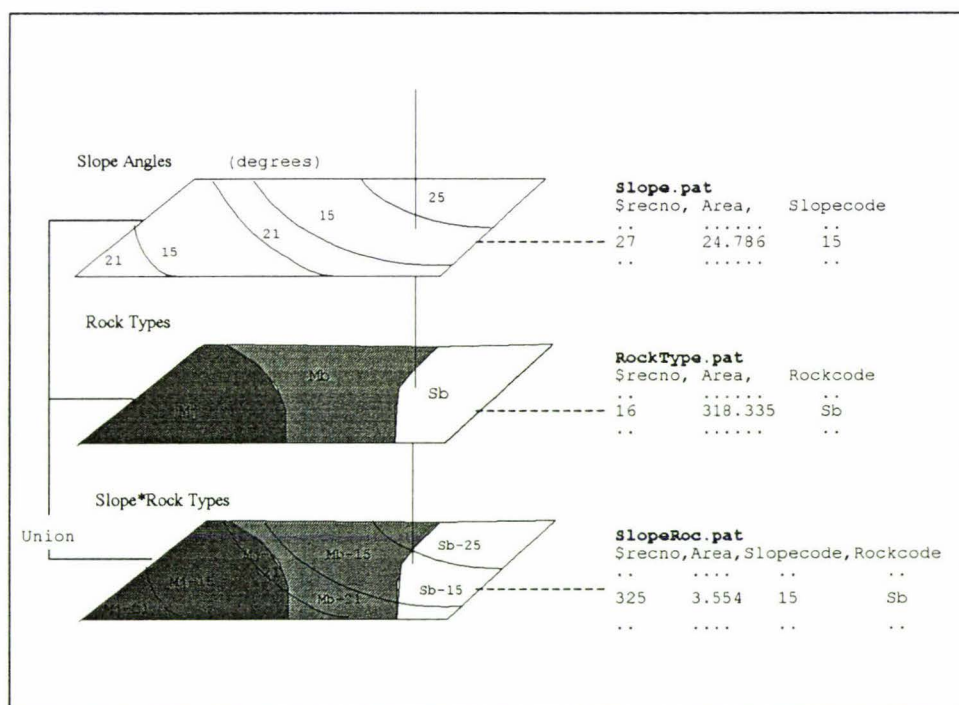


Figure 6.2 Overlay ('union') procedures and associated database polygon attribute tables.

Area calculations were carried out using the ARC/INFO statistics facilities to provide summaries of the areas of each class or combination of classes in the layer. These were then manually calculated to obtain the percentage of each feature class which had been

affected by soil slip during Cyclone Bola. An example of these workings is shown in table 6.1. Areas which were identified as flat were also excluded from the calculation of soil slip per aspect as they could not be distinguished as river flats, terrace treads or broad ridges without further analysis. During the classification process areas of soil slip and flooding (water and silt) could not be differentiated. Aerial photographs showed there to be little soil slip on flat areas but deposition of silt on river flats.

	ASPECTS		
	Ha. total Aspect	Ha. Soil Slip	%
Flat	312.15	N/A	N/A
North	200.48	23.82	11.88
Northeasterly	355.55	53.13	14.94
Easterly	436.01	32.13	7.37
Southeasterly	540.78	17.31	3.20
Southerly	343.43	5.44	1.58
Southwesterly	318.13	6.61	2.08
Westerly	237.20	9.80	4.13
Northwesterly	<u>157.87</u>	<u>16.83</u>	10.66
	2901.60	178.89	

Table 6.1 Calculation of the areal extent of each aspect that was affected by soil slip during Cyclone Bola, 1988.

6.4 RESULTS AND DISCUSSION

6.4.1 Slope Aspect

The variation amongst the percentages of land area within each slope aspect class on Emerald Hills station (Figure 6.3) reflects the geologic control on the land in the East Coast region. There are longer gentler, southeasterly facing dip slopes and shorter, steeper, northwesterly facing scarp slopes.

However, the density of soil slip per aspect class is greatest for NE aspects (14.9%) followed by N (11.9%), NW (10.7%) and E (7.4%) aspects, and much less for SE aspects (3.2%) (Figure 6.3).

These results are consistent with previous studies in the area (Veld and de Graaf, 1990) and in the Wairarapa (Crozier *et al.*, 1980) which determined the slope aspect at soil slip sites by field measurement.

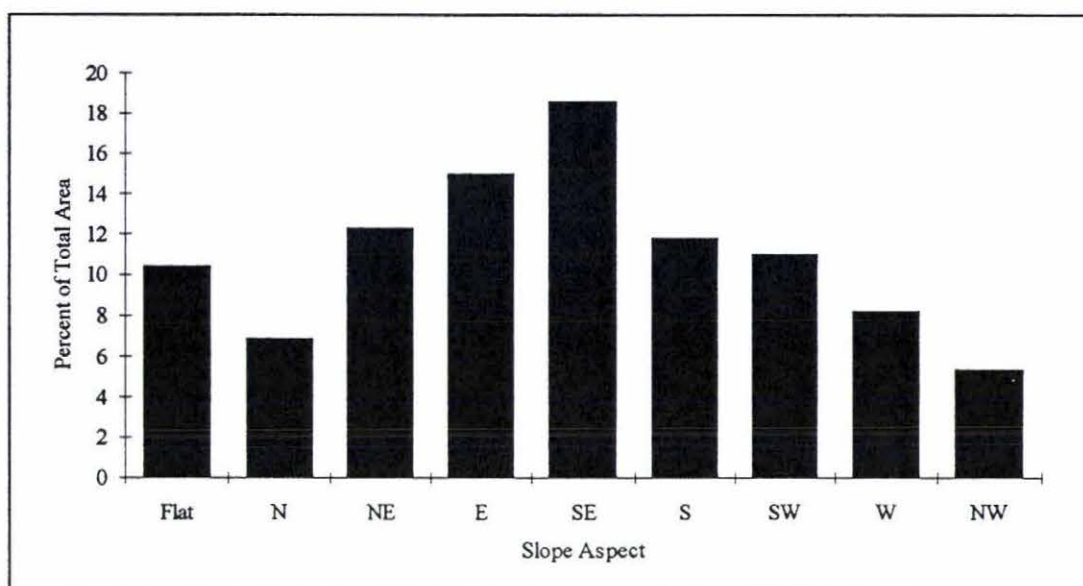


Figure 6.3 The distribution of slope aspects on Emerald Hills station

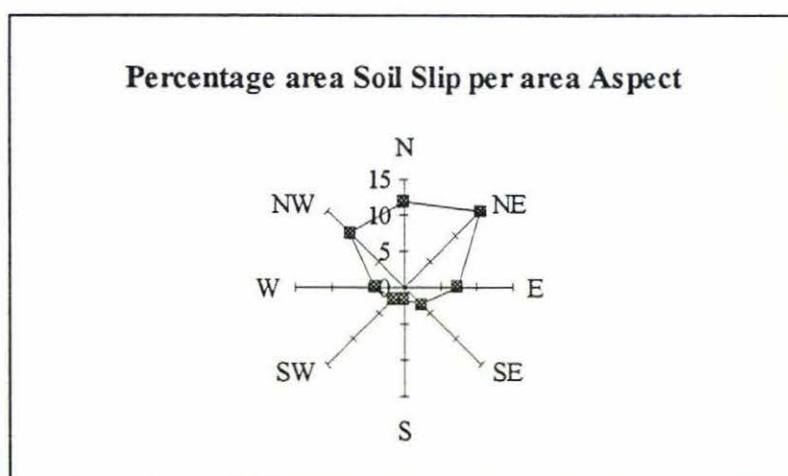


Figure 6.4 The extent of soil slip in each slope aspect

6.4.2 Slope Angle

The majority (60%) of the land on Emerald Hills station is strongly rolling to steep (16° - 35°). Of the remaining, 8% is very steep ($>35^\circ$) and 32% is flat to gently rolling ($<15^\circ$) (Figure 6.5). The flat areas include ridge tops, river terraces and flats.

As slope angle increases so does the percentage of soil slip (Figure 6.6). This trend is in agreement with other studies (Eyles *et al.*, 1978, De Rose *et al.*, 1993,). However, where other studies have identified a critical angle below which soil slip does not occur, results from this study show there to be no critical slope angle. Soil slip can occur at any angle. Because of the scale of the contour data (20m) small

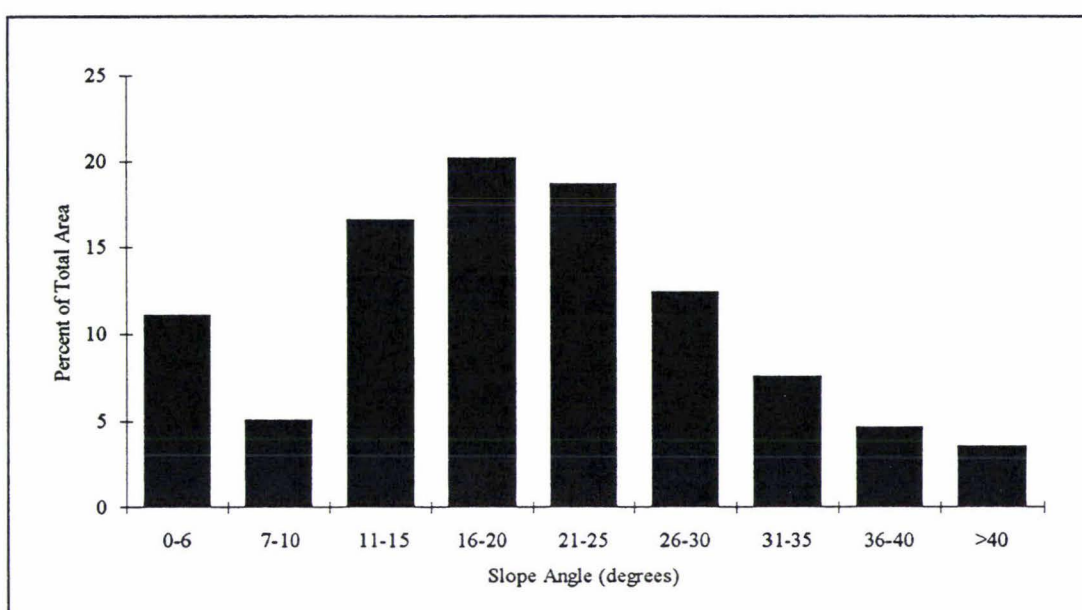


Figure 6.5 The distribution of slope angles on Emerald Hills station

changes in slope angle have not been identified. For instance, a slope with a general slope angle of 8-15 degrees may have within it small areas of lesser or greater slope angle. The soil slip recorded in that general slope may in fact be occurring in sites with greater than 15° slope angle. There is a gradual increase in the amount of soil slip as slope angle increases, to a maximum at 27 - 30°. The amount of slip does not increase on slopes over this steepness.

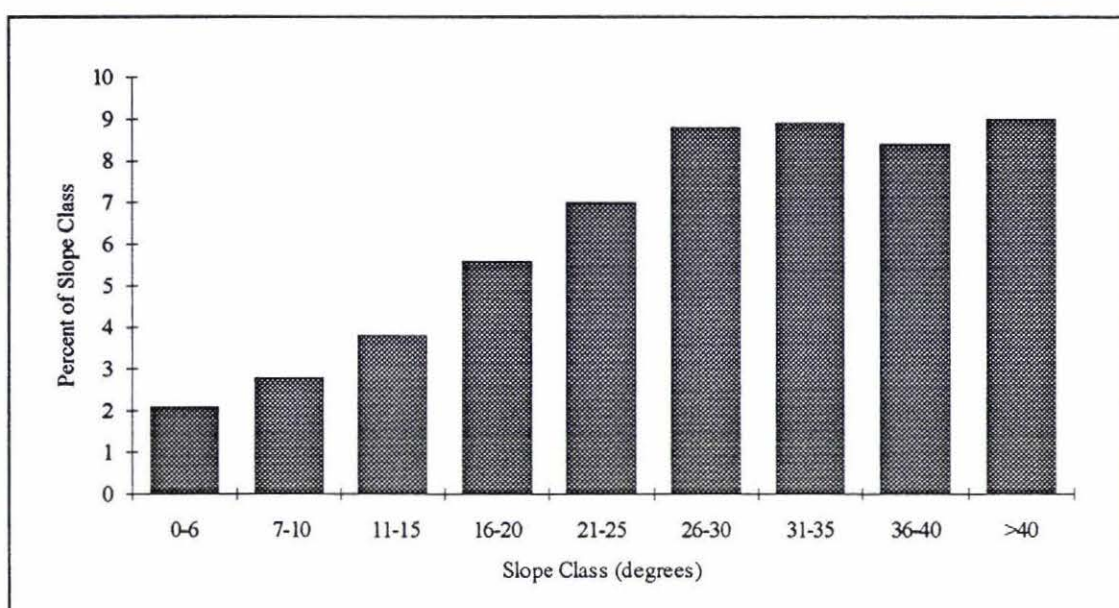


Figure 6.6 The distribution of soil slip per slope angle class

Sequential aerial photograph and field inspection showed that the majority of the Cyclone Bola soil slips in the study area occurred in positions that had been subject to slipping since before 1945. The earliest photography available was 1945 by which time considerable soil slipping had occurred to form a landscape of 'lumpy' slopes and sharp ridges. It was not possible to determine the position of the slope where soil slip occurred. The scale of contour information available (20m) was not detailed enough to investigate microtopographic land elements (hillslope spurs and swales) using a DEM. Stereo viewing of aerial photos showed that the majority of slips occurred on concave hillslopes. Many occurred along the upper margin swales but many more occurred haphazardly throughout the hillslope.

6.4.3 Slope Angle per Aspect

To investigate whether the increased soil slip in the northerly and easterly aspects was a function of the slope angles within those aspects, the two layers were combined. This produced a layer of areas with consistent slope aspect and slope angle. The distribution of slope angle within each slope aspect was then determined (Figure 6.7).

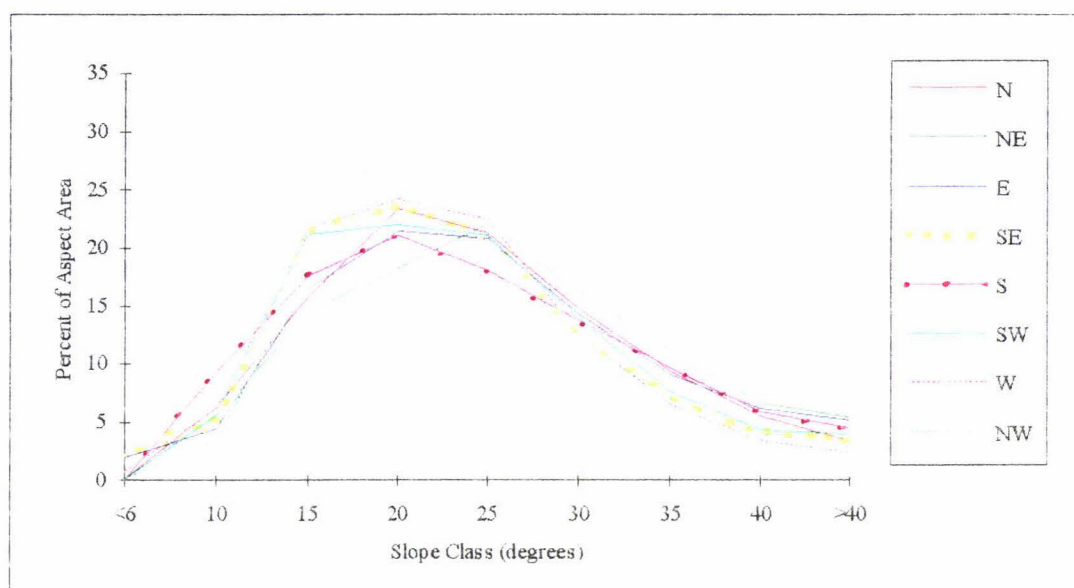


Figure 6.7 The distribution of slope class per aspect

There was little variation in the distribution of slope angle classes across the aspects with the exception of NW aspects which had a higher percentage of strongly rolling slopes (16 - 20°) than other aspects. NE aspects had a lower percentage of rolling to strongly rolling slopes (11 - 20°) than other aspects and a slightly higher percentage of steep slopes.

The density of soil slip within each of these units was then calculated by dividing the area of soil slip within each unit by the total area of each unit (slope angle*aspect), and expressing the results as a percentage (Figure 6.8). The density of soil slip is greater on the steeper NE, N, NW, and E aspects than on other aspects which show less variation in the density of soil slip across the units. This reiterates the fact that the greatest density of soil slip occurred on steeper slopes over 20° (Figure 6.6) and on NE, N, NW and E aspects (Figure 6.4). NE, N, NW and E aspects do not have a greater percentage of slopes over 20° than other aspects (Figure 6.7) and therefore, slope angle alone cannot describe the predominance of soil slip on these aspects.

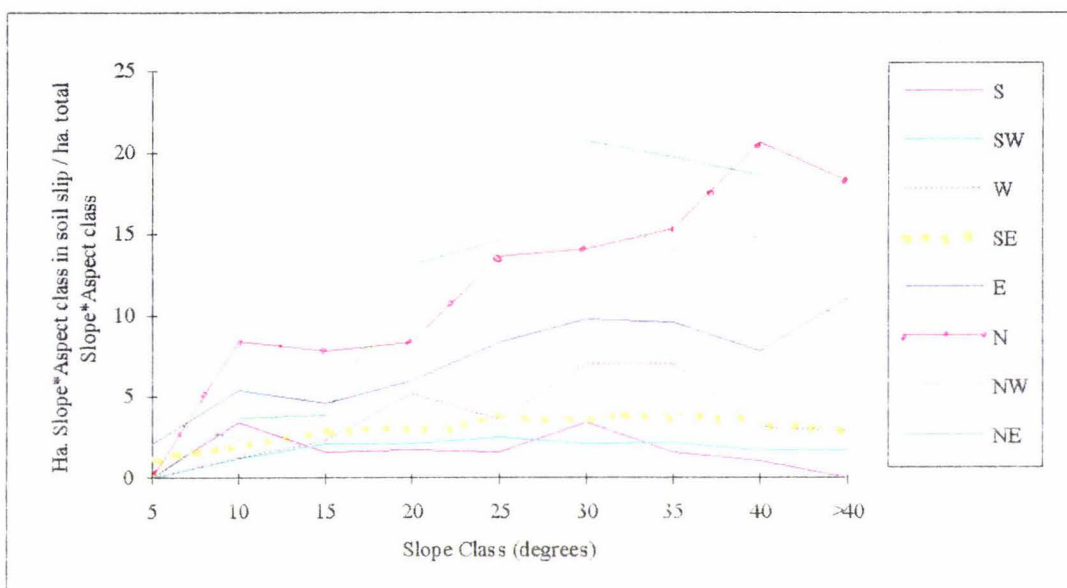


Figure 6.8 The density of soil slip on Slope*Aspect classes

6.4.4 Rock Type

The soil slip in the area was found, by Veld and de Graaf (1990), to occur within the regolith, often, but not always exposing the underlying rock type. The regolith where soil slip occurred was found to be mainly colluvium. Therefore, it was questionable whether the underlying rock type has any influence on the susceptibility of the slope to fail other than its influence on slope angle and the provision of a less permeable layer on which the overlying saturated material may slide.

The following results show that there is a relationship between the type of underlying rock and the density of soil slip erosion. By far the most extensive rock type mapped on the Emerald Hills station farm plan is jointed mudstone (43%) (Figure 6.9).

Jointed mudstone had the greatest density of soil slip (7.9%), followed by massive mudstone (6.9%), banded mudstone (6.4%), and crushed mudstone (5.2%), (Figure 6.10). The least soil slip was found on areas with a layer of tephra at or near the surface. Areas underlain by banded sandstone had less soil slip than areas underlain by mudstone.

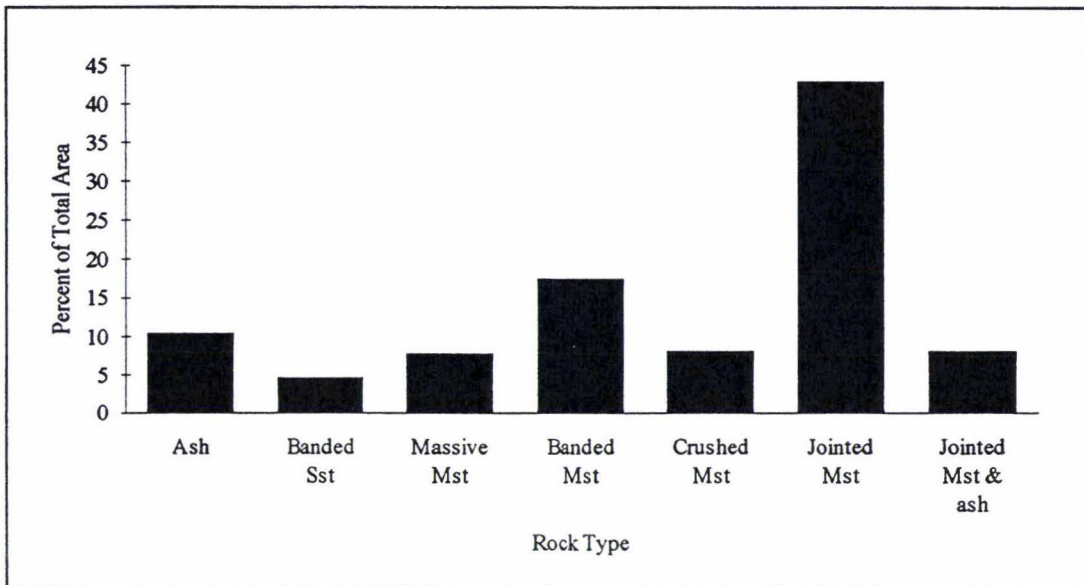


Figure 6.9 The distribution of rock types on Emerald Hills station

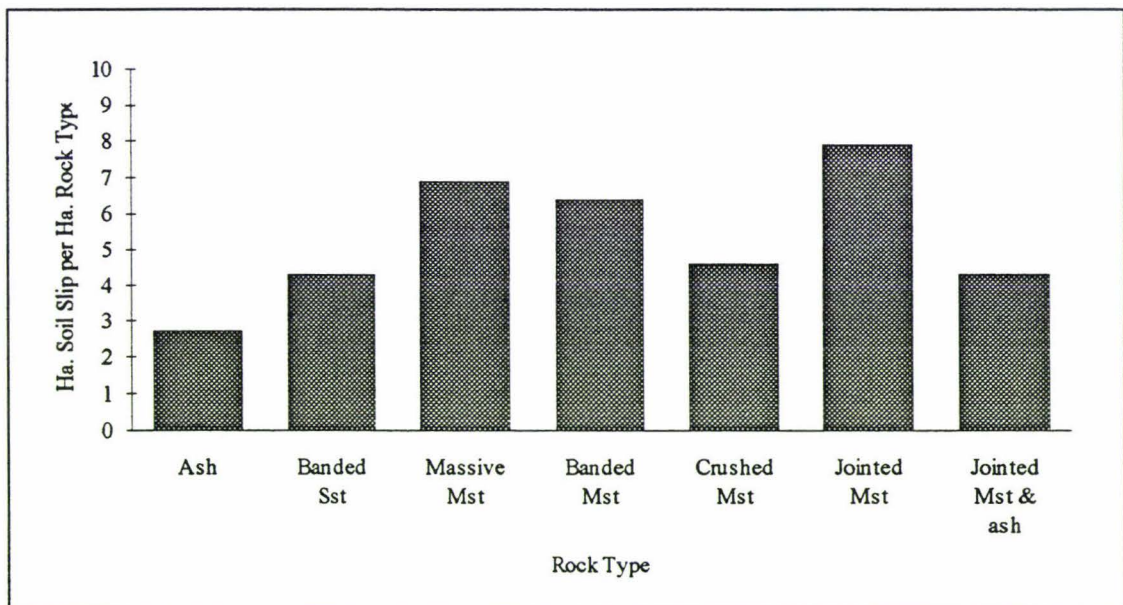


Figure 6.10 The density of soil slip per rock type

These results are consistent with the findings of other studies (Crozier *et al.*, 1980) even though it is expressed by some (Crozier *et al.*, 1980, Veld and de Graaf, 1990) that slipping occurs within the regolith and bedrock has little direct significance on its distribution.

Those areas of the farm mapped as being underlain by a mixed rock type class, jointed mudstone and tephra, exhibit lower soil slip densities. The lower soil slip densities of areas with a layer of tephra modifies (downwardly) the overall density value of the class. Gage and Black (1979) inferred that an intact cover of coherent Waiohu Ash was able to moderate the erosive effects of run-off. Part of this effect can be attributed to its greater water storage capacity compared to mudstone. Following field mapping of lithologies carried out for this project, there is some concern regarding the accuracy of the delineation of tephra on the farm plan. Tephra was found to occur only in stable sites, not continuously over large areas as mapped. The mapping of lithologies on the farm plan also included a differentiation between crushed mudstone and jointed mudstone and it has been determined by these analyses that the density of soil slip is lower on the crushed mudstone. Crushed mudstones are found along faults and the syncline but the criteria for identifying crushed mudstone on the farm plan is not clearly defined. It is possible that there is some overlap in the way these rock types were identified and then reported in the field.

6.4.5 Slope Angle per Rock Type

The distribution of slope angle within each rock type was also investigated to ascertain whether this could account for the variation of soil slip density between rock types (Figure 6.11).

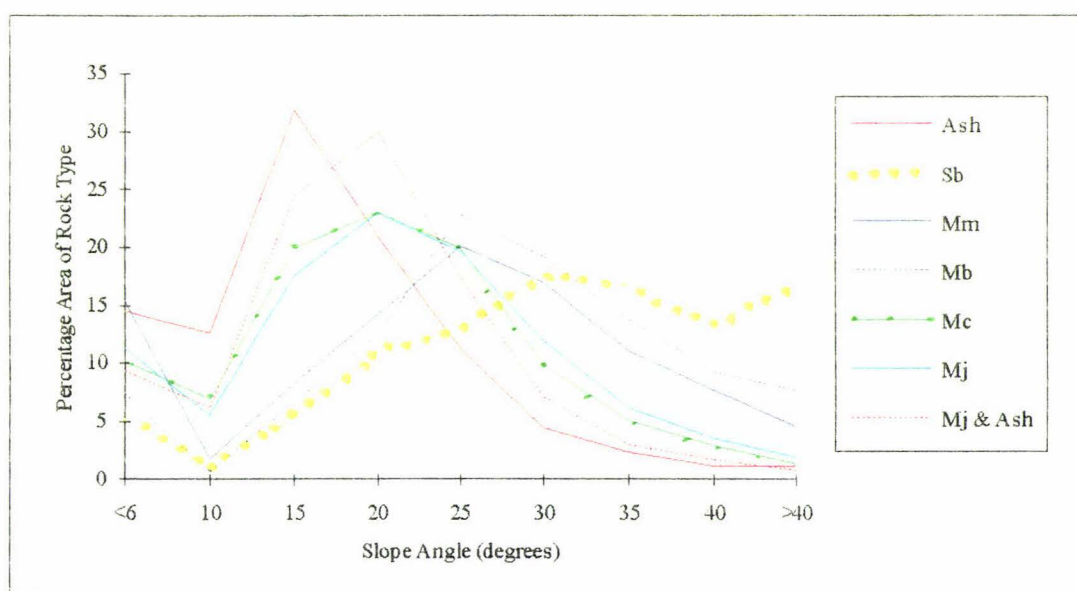


Figure 6.11 The distribution of slope angle per rock type

Areas underlain by banded sandstone occur in higher proportions on steeper slopes. Areas with a layer of tephra or the inclusion of tephra (jointed mudstone and ash) are found on gentler slope angles. Whilst the density of soil slip on jointed mudstone was much greater than on crushed mudstone (Figure 6.10), the distribution of slope angles within these two rock types does not vary significantly and therefore cannot explain the difference in soil slip density between rock types.

Earthflows are the form of erosion most commonly associated with crushed mudstone (Hamilton and Kelman, 1952). If the areas underlain by crushed mudstone had previously been modified by earthflow they could be expected to now be comprised of lower angled slopes. On crushed mudstone there are a slightly higher proportion of slopes with a lower slope angle than on jointed mudstone and, a slightly less proportion of slopes with a higher slope angle (Figure 6.11). This variation in slope angle distribution is not thought to be great enough to explain the difference in soil slip density between the two rock types.

The incidence of soil slip has been shown to increase with slope angle (Figure 6.6). Banded and massive mudstone, and banded sandstone, have a higher proportion of steeper slopes than jointed mudstones yet, jointed mudstone exhibits greater soil slip density. Therefore, slope angle does not explain the greater density of soil slip on jointed mudstone.

6.4.6 Rock Type per Slope Aspect

The greatest density of soil slip occurs on NE, N, NW and E aspects (Figure 6.4). The greatest density of soil slip also occurs on jointed mudstone (Figure 6.10) with slightly lesser densities of soil slip on massive and banded mudstone. To investigate whether there was a higher proportion of jointed, massive or banded mudstones on NE, N, NW and E aspects the layers of rock type and slope aspect were combined and analysed. The occurrence of each rock type (%) within each aspect class was determined (Figure 6.12).

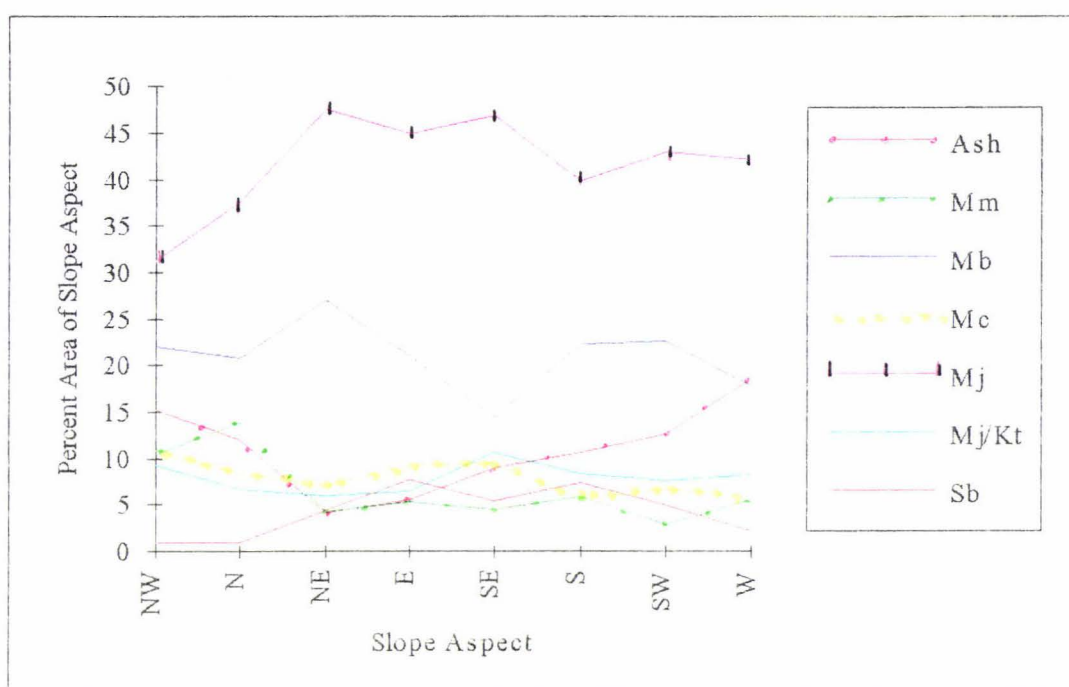


Figure 6.12 The distribution of rock type per slope aspect

Jointed mudstone is the most dominant rock type in all aspects. The variation in percentage area of each aspect underlain by jointed mudstone is less than 10%, except for northwesterly aspects which have much less of their area underlain by jointed mudstone. Northeasterly and Southeasterly aspects have the same percentage of their area underlain by jointed mudstone yet the percentage of soil slip on northeasterly aspects was 14.9% compared to 3.2% on southeasterly aspects. There is a slightly greater variation (13%) in the percentage of banded mudstone within each aspect. 27% of northeasterly aspects are underlain by banded mudstone compared with 14% of southeasterly aspects. Northerly and northwesterly aspects have more of their area underlain by massive mudstone than other aspects; 14% of northerly and 10% of northwesterly aspects compared with less than 6% of all other aspects.

Northerly, northwesterly and easterly aspects have more of their area underlain by jointed, banded or massive mudstones than other aspects (Table 6.2).

Percent of Slope Aspect underlain by jointed, banded or massive mudstone	
	%
NW	63.7
N	72.0
NE	78.7
E	71.1
SE	65.7
S	67.9
SW	68.3
W	65.3

Table 6.2 The extent of the jointed, banded, and massive mudstone per slope aspect.

This might suggest that the extent of these lithologies has an influence on the susceptibility of slopes to soil slip erosion but, northwesterly aspects (which also sustained a high density of soil slip) have the least of their area underlain by these lithologies.

The presence of tephra has been shown to reduce the incidence of soil slip (Figure 6.10). Westerly aspects have the greatest occurrence of tephra (18% of their area). They also have a low density of soil slip (4%) compared with that of northeasterly aspects (15%) which have the least area of tephra cover (4%). However, other aspects which have a high density of soil slip (northwesterly and northerly) also have more than 12% of their area underlain by tephra.

Although the type of underlying rock affects the proneness of the land to soil slip erosion (Figure 6.10), the distribution of rock types within NE, N, NW and E aspects cannot explain the higher density of soil slip measured on these aspects.

6.5 DISCUSSION

By using the data manipulation and analysis capabilities of GIS it has been possible to investigate the relationships between the soil slip erosion and the inherent physical factors within a landscape.

A greater amount of soil slip occurs on slopes with northerly and easterly aspects. As slope angle increases there is a concomitant increase in the amount of soil slip. There is no increase in the density of soil slip on slopes with a slope angle over 30°. In variance with other reports (Crozier *et al.*, 1980, Lough, 1993) there is no noticeable critical slope angle below which there is no soil slip. Some soil slip occurred on slopes of all steepness. There is, also, a relationship between the amount of soil slip per area and the underlying rock type with mudstone being more susceptible to soil slip erosion than sandstone. The occurrence of soil slip is lower on surfaces underlain by tephra. These slopes are predominantly of low angle (<15%).

This study has not identified a reason for the predominance of soil slip on slopes of northerly and easterly aspects. Other workers (Phillips, 1988; Crozier *et al.*, 1980) have shown that most soil slip occurs on upper slopes with a northerly or easterly aspect. Crozier *et al.*, (1980) put forward the proposal that there may be more undisturbed regolith of greater depth on the sunny (N and E) slopes because erosion processes have operated more frequently (seasonally) removing regolith on the wetter, shadier slopes (S and W). This would corroborate with the findings made in this study that the predominance of soil slip in the study area occurs on steeper slopes with northerly and easterly aspects.

In their investigation into the distribution of soil slip in the same catchment, Veld and de Graaf (1990) carried out field measurements along transects. They found that steep slopes of northerly aspect had the greatest density of soil slip and concluded that north facing slopes in their study area were steeper than other slopes. North facing slopes have not been found to be any steeper over all in this study.

The density of soil slip per aspect (Figure 6.4) suggests there may be a relationship between the incidence of soil slip and radiance levels. The aspects which have the highest incidence of soil slip (NE, N, NW, E) are also those that receive the most radiance. Possible reasons for this include the poorer condition of summer pasture and the greater likelihood of surface cracking on these aspects. Poorer vegetative cover exposes more soil surface to rain-drop impact. Fine particles block soil pores reducing

infiltration rates and increasing surface runoff. The clay soils of the area crack during dry periods. During a rain storm the cracks allow deep infiltration and saturation of the soil at depths where there is low permeability. Slope collapse (slip, slump, earthflow) then occurs.

Further studies are required to investigate the distribution of soil slips in relation to microtopographic land elements (more detailed changes in slope angle) and surface conditions. Whilst these studies will involve field surveys, a GIS would be useful for the storage and analysis of the data. A DEM derived from contour data of a larger scale would improve the integrity of the analyses investigated in this study.

CHAPTER VII

LAND USE CAPABILITY MAPPING

7.1 INTRODUCTION

The LUC classification is the most widely used system, in New Zealand, for describing the suitability of land in terms of sustainable use. LUC surveys are used to assist land use planning by local and government authorities. Many government initiatives designed to encourage sustainable land use and reduce erosion (e.g. East Coast Conservation Forestry Scheme, 1989; East Coast Forestry Project, 1993) have been based on LUC information.

In carrying out their duties of promoting sustainable land management as set out in the RMA, planners and managers require accurate and sufficiently detailed information about the resources under their control. The only LUC information that is available for all of New Zealand is the NZLRI LUC classification. Much of the information contained in these maps was taken from previous small-scale surveys (e.g. 1:250,000 geological surveys).

In this chapter the success of the LUC classification with respect to its ability to describe the distribution of Cyclone Bola soil slip erosion is investigated, and an attempt is made to improve the detail of LUC information.

7.2 LAND USE CAPABILITY MAPPING IN NEW ZEALAND

In the 1940's K.B. Cumberland, a soil conservator for the North Canterbury Catchment Board advocated the need for a land survey and classification system as a basis for future conservation measures (Cumberland, 1944). A system was needed that not only identified present erosion but also provided physical information that could be utilised to assess the long term capability of the land to sustain production. In 1952, the Soil Conservation and Rivers Control Council (SCRCC) adopted a modified American, eight class, LUC classification and mapping system to aid the planning of erosion

control practices and land usage to obtain high and sustainable production (McCaskill, 1973). The main modification made to the American system was the change in emphasis from an interpretation of soils to one of interpreting the land.

Land use capability is "the systematic arrangement of different kinds of land according to those properties that determine its capacity for permanent sustained production" (SCRCC, 1971). Capability means the potential of land for use in specified ways, or with specified management practices (Dent and Young, 1981). It involves grading the land from best (Class I) to worst (Class VIII) assuming arable use to be the most desirable. The land is classified on the basis of permanent physical limitations that adversely affect the capability of the land and which cannot easily be changed. Land that is allocated to any particular capability class has the potential for the use specified for that class and for all classes below it. The capability class does not necessarily indicate what is the best use for land, nor the most profitable. Because it is biased towards soil conservation considerations it lends itself to sustainable land use planning.

Following the guidelines of the "Land Use Capability Survey Handbook" (SCRCC, 1971) detailed resource surveys are carried out by catchment authority soil conservators as part of farm soil and water conservation plans. These inventories are carried out in the field by recording directly onto aerial photographs or maps facts about the soil, rock type, slope, erosion, land use, and vegetation. Distinct land inventory units are then delineated on a land inventory map.

The land inventory units defined by the field survey provide the basic information for the land use capability classification. This classification provides three categories of groupings of the inventory units; a capability class, subclass and unit. The major grouping of eight land use capability classes gives information about the general limitation of the land (the total degree of limitation). The second category, the capability subclass provides for a grouping of units with the same kind of limitation or hazard; e (erodibility), w (wetness), s (soil limitations within the rooting zone), and c (climate). The third category, the land use capability unit, groups those inventory units

that respond similarly to the same management, are suitable for the same use, and require the same conservation measures.

The LUC units of Emerald Hills station as mapped (at 1:10,000) during the completion of a conservation farm plan are shown in Figure 7.1.

7.2.1 New Zealand Land Resource Inventory

Using the above system a land resource inventory and LUC classification for all of New Zealand (the NZLRI) was completed in 1978, at a scale of 1:63,360. This was intended particularly for use in relatively detailed planning at a regional level (Eyles, 1975). It is publicly available in the form of worksheets (maps) with extended legends or as computerised products (maps or on disk). A full description of the NZLRI is given in "Our Land Resources" (NWASCO, 1979). Some of the information in the inventory was mapped at a very small scale. The rock type information for the relevant worksheet, Tiniroto N 106, is adapted from the N.Z. geological Survey Map, sheet 9, of 1:250,000 scale and a survey of soils and rock types by O'Byrne (1967) at scale 1:126,720. The resource information is intended to be updated as necessary. Currently, the surface vegetation information is being updated from a Landsat TM image (L. Brown, Landcare Research. Pers Comm.).

The majority of land does not have detailed resource maps (e.g. soil and water conservation farm plans) and regional planners have expressed the need for the land units of the NZLRI to be more detailed to facilitate planning at farm scales.

Currently, Landcare Research is attempting to improve the detail of the land units of the NZLRI using DEMs and automated mapping (Dymond and Harmsworth, 1994; Dymond et al., 1995). LUC classes were mapped in the Gisborne-East Cape region by identifying slope components within land systems (areas with uniform rock and erosion characteristics), using a DEM and correlating each component to a LUC class (Dymond and Harmsworth, 1994). The resulting map had an 80% agreement with manually-derived LUC maps of 1:25,000 scale. The scale of the automatic mapping is still of insufficient detail for farm scale land use planning which is related to LUC units.

But, as the scale of DEMs improve so will the detail of the resource information on the NZLRI.

Other land resource attributes (e.g. soil type) can be automatically assigned by land attribute-landscape models. Soils were mapped in the Gisborne-East Cape region using a soil-landscape model involving land components which were mapped from a DEM (McLeod et al., in press). Once again, due to the scale of the DEM, the highest accuracy was in the mapping of the more generalized soil classes. Soil order, group and subgroup were predicted with accuracies of 86, 76 and 57% respectively.

The LUC units for Emerald Hills station taken from the NZLRI are displayed in Figure 7.1.

7.2.2 Gisborne District Council Erosion Categories

A modification of the NZLRI LUC classification was carried out in the "Red Report" to describe areas of land in the East Cape region recommended for certain land uses (Poverty Bay Catchment Board, 1978). The four classes in this classification are termed Gisborne District Council Erosion Categories. The relationship between these categories and the NZLRI LUCs is shown in Table 2.2. These Erosion Categories are often used in preference to LUC units to describe land use planning and management in the East Coast region. For example, the East Coast Forestry Project favours the planting of exotic production forestry on category 3 and the more eroding Class 2 land.

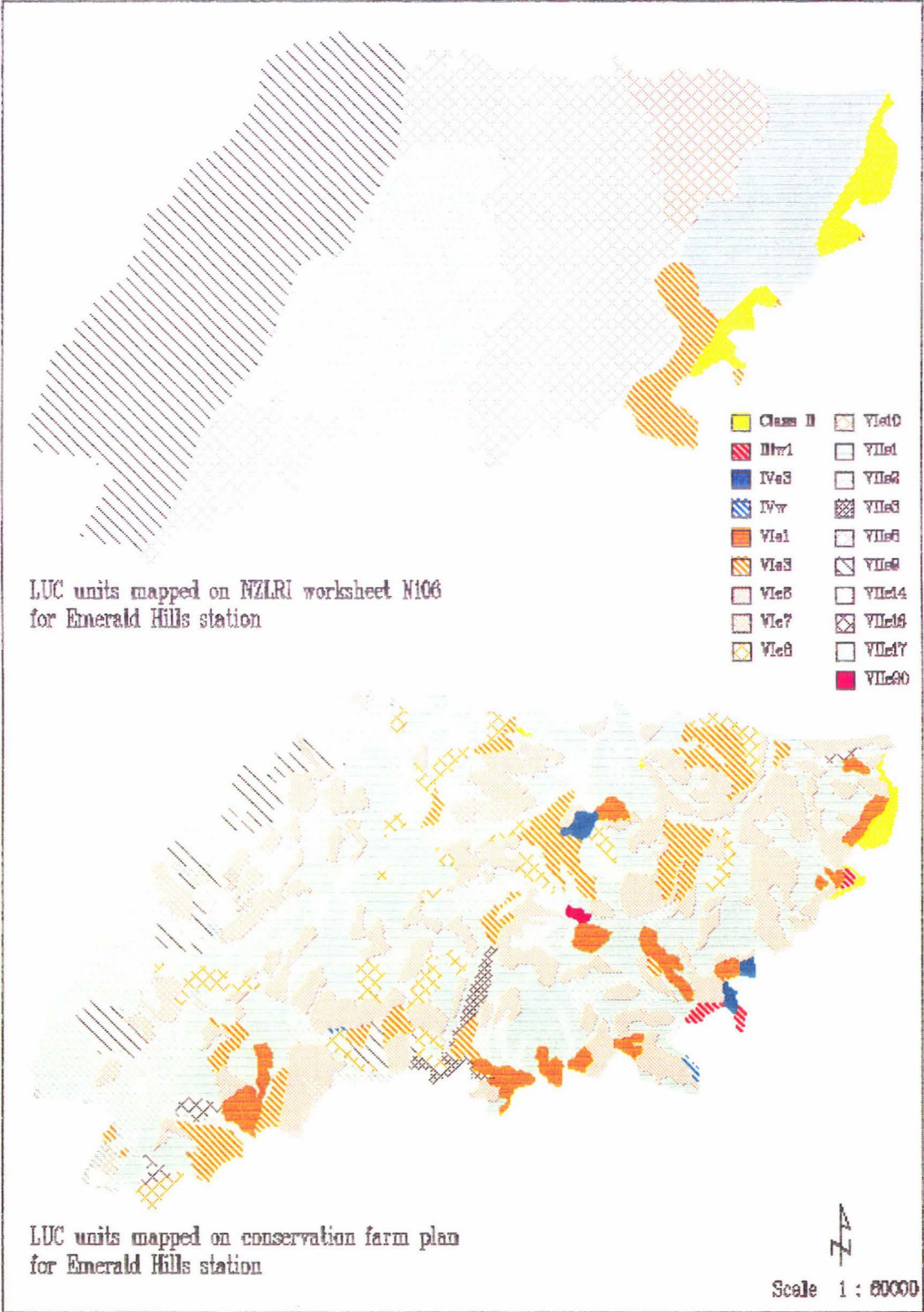


Figure 7.1 A comparison of LUC mapping for Emerald Hills Station on the NZLRI and on the GDC farm plan.

7.3 THE SUITABILITY OF THE LUC CLASSIFICATION FOR DESCRIBING LAND WHICH IS PRONE TO SOIL SLIP EROSION

To assess the relationship between the LUC mapping system and the distribution of soil slip following Cyclone Bola, the detailed LUC map (1:10,000) for Emerald Hills station was 'intersected' by the soil slip map. This produced a map of the areas of soil slip only along with information relating to the LUC units on which they occurred.

The percentage area of each LUC Unit which sustained slipping is shown in Figure 7.2.

The LUC units are an assessment of the capacity for sustained productive use of that area of land delineated by the units. They describe the decreasing versatility and increasing degree of physical limitation to sustained use. The major kind of limitation to sustained use on Emerald Hills station is erosion (e). In determining the degree of limitation, all forms of erosion are assessed at the time of mapping. Soil slip is only one form of erosion which influences the degree of limitation.

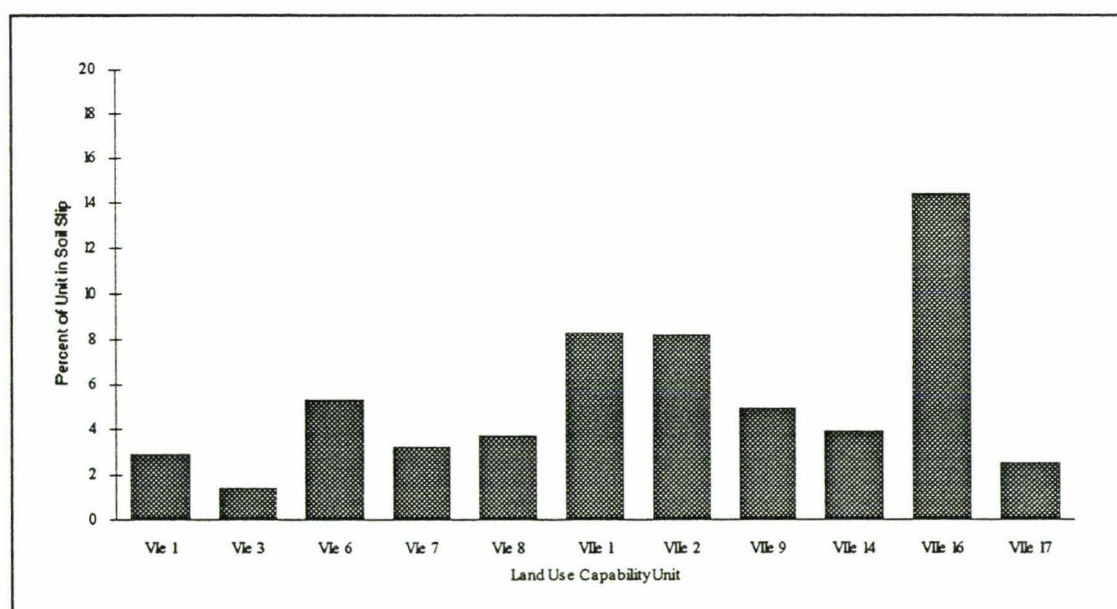


Figure 7.2 The distribution of soil slip per LUC Unit

Among the Class VI units, Vle1 has more soil slip than Vle3; and Vle6 has much more soil slip than other Class VI Units and some Class VII Units. Vle1 is mapped on 16-25o (D+E) slopes of jointed mudstone in basins.

VIe3 is supposedly mapped on ridges of the same steepness as VIe1 but where tephra overlies mudstone. The farm plan shows that VIe3 is not only mapped on ridges, but on slopes of 16-25° where tephra is observed. VIe1 is mapped on slopes of similar steepness where there is no tephra. That tephra still remains suggests that these slopes are not as steep as estimated, and are certainly less steep than those mapped as VIIe1. The areas mapped as VIe3 are delineated on the slope information derived from 20m contours (Figure 7.3). According to this slope information the slopes of VIe3 are mostly less than 21°. The slope information generated by the TIN tends to smooth the slopes. Small changes in steepness are not identified because of the contour spacing, 20m. However, ground truthing favoured the TIN generated slope information over the farm plan slope information. Most areas mapped as VIe3 are less steep than stated on the farm plan. Within the areas of VIe3, where the slopes were as steep as stated, there was nearly always a lack of tephra cover.

VIe6 is mapped on jointed or crushed mudstone at the head of catchments where slope angles are 16-35°. Whilst Units VIe7 and VIe8 are also mapped on slopes of up to 35°, VIe7 is mapped on banded mudstone and VIe8 is mapped where tephra overlies the mudstone. Both these rock types have been shown in this project to sustain less soil slip than jointed mudstone (Figure 6.10).

In Class VII, Units mapped as having a higher degree of limitation (Units VIIe14, VIIe9 and VIIe17) had less soil slip than other Class VII units. Unit VIIe14 contains areas of stream channels with gully erosion but not so much soil slip erosion. These areas were previously considered to be the most problematic in terms of erosion and at the time of Cyclone Bola had mature conservation plantings to protect them. Although a low percentage of bare ground has been portrayed in these areas by the remotely sensed data, ground truthing revealed that the gullies are still eroding in some places beneath the tree cover and that the detritus from the eroded open slopes has infilled many of the stream beds destroying or overtopping the debris dams.

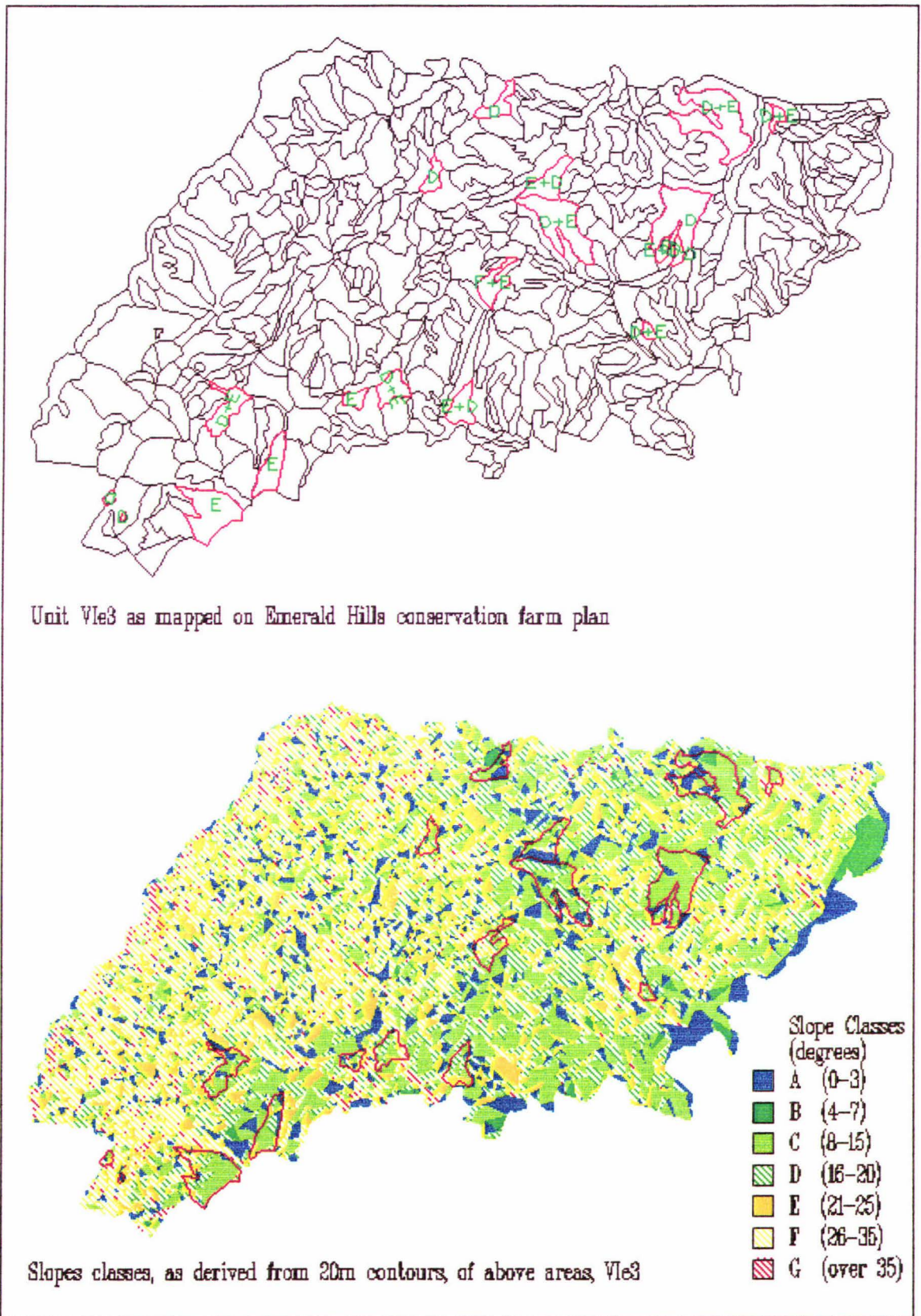


Figure 7.3 A comparison of slope information for areas mapped as Vle3

Units VIIe9 and VIIe17 are mapped on the steep banded sandstone slopes at the back of the property which being too difficult to farm have been allowed to revert to bush, the bush cover again giving protection to the slopes during heavy rainfall.

Only soil slip erosion has been included in this investigation of erosion. The classification of the land's capability to sustain use is based on all forms of erosion. VIe1 and VIe3 have similar slope angles and natural fertility but VIe3 is described as having more types of erosion. Tunnel gully is more prevalent on the tephra covered slopes. Because of this VIe3 has a slightly lower capability to sustain intensive grazing than VIe1.

LUC units may be interpreted to reflect erosion susceptibility but they are also used to describe the overall versatility of the land for use based on other criteria, e.g. fertility. Units VIe7 and VIe8 sustained less soil slip than VIe6 but they also have lower natural fertility and are therefore less capable of sustaining the same intensity of use as VIe6. Although the higher Class VII Units, VIIe9 and VIIe17, sustained low soil slip erosion during Cyclone Bola they also have a low capacity for agricultural use due to their steepness and the low physical fertility of the underlying sandstone.

7.4 LUC MAPPING USING THE GIS

Resources are not always available for the mapping of land inventories at the farm scale and regional planning is often completed using the information available in the NZLRI. As already stated, much of this information has been compiled from small-scale maps. It would be very convenient if the NZLRI information could be improved using more detailed information as it becomes available. Digital contour information is now available for all New Zealand at 20m contour intervals, and for some areas at 5m contour intervals.

This section investigates whether inventory information can be improved by using more detailed slope data generated from 20m digital contours in the TIN module associated with PC ARC/INFO.

In completing the NZLRI, independent surveys were carried out in each of 10 regions in the North Island, each with its own LUC classification. The LUC units in any one region are numbered independently of those in other regions. Often similar land was assigned different LUC units in different regions. The study area was surveyed as part of the Northern Hawkes Bay LUC classification region. It is administered by the Gisborne District Council who use the Gisborne-East Coast region LUC classification for LUC mapping. A correlation of the North Island LUC units is available to identify those units in the 10 regions that are essentially the same or similar (Page, 1985).

For the purposes of this study a refined LUC capability classification (Table 7.2) was composed based on the Gisborne-East Coast Region Land Use Capability classification (Table 7.1). The units therefore, are not the same as the LUC units stated on the NZLRI map for Emerald Hills station. The abbreviations used for erosion type and degree are consistent with those used on the NZLRI worksheets legends (NWASCO, 1979).

Description of LUC units from the Gisborne-East Coast NZLRI extended legend			
LUC	Lithology	Slope	Erosion
Vle6	Mj	E+F	2sSl, 1eF, 1G
Vlle1	Mj	F+E	2sSl, 2eF, 2G, 1Su
Vlle3	Mj (loose)	E+D	1sSl, 4eF, 3G
"	"	E+F	" "
Vlle14	Mj (loose)	E,F,G	2sSl, 4eF, 4G, 3Su
Vle1	Mj or Mb	D+E	1sSl, 1eF
Vlle16	Mj or Mb	F+G	4sSl, 3G, 3Sh
Vle7	Mb	E+F	1sSl, 1Sh
Vlle2	Mb	F+G	2sSl, 1Sh
Vle10	Sst	E+F	1sSl
Vlle9	Sst	F+G	1sSl
Vlle17	Sst	G	1sSl

Table 7.1 The Gisborne-East Coast region LUC classification description of the Units used in the revised schedule (below)

Schedule for Assigning Revised LUC Units				
LUC	Lithology	Slope	Erosion	if on NW,N,NE,E aspects
II	Alluv	all	nil	
VIe1	Mj	A-D	1sSl, 1eF	VIe6
"	Mb	A-D	1sSl, 1Sh	VIe7
VIe6	Mj	A-E	2sSl, 2eF, 1G, 1Su	VIIe1
"	Mj	E	1sSl, 1eF	VIIe1
"	Mj	A-C	>2sSl, >2eF, >1G, >1Su	VIIe1
VIIe1	Mj	F+G	1sSl, 1eF,	VIIe3
"	Mj	F	2sSl, 2eF, 1G, 1Su	VIIe3
"	Mj	D+E	>2sSl, >2eF, >1G >1Su	VIIe3
VIIe3	Mj	G	2sSl, 2eF, 1G, 1Su	VIIe3
VIIe3	Mj	F+G	>2sSl, >2eF, >1G, >1Su	VIIe3
VIe7	Mb	E	1sSl, 1Sh,	VIIe2
VIIe2	Mb	F+G	2sSl, 2Sh	VIIe16
VIe10	Sst	A-E	1sSl	
VIIe9	Sst	F	1sSl	
VIIe17	Sst	G	1sSl	

Table 7.2 Revised description of LUC units used in this study.

7.4.1 Revised LUC mapping using NZLRI lithology and erosion, and TIN generated slope angles

Lithology and erosion information was extracted from the NZLRI and combined with the slope class information generated from the TIN. LUC units were assigned according to the properties described in the revised description of the units,

Table 7.2.

There is no attempt to subdivide Class II land into units because these are based on physical attributes of the soil that must be ascertained in the field. The overall purpose of this study is to determine whether detailed LUC mapping can be accomplished using a GIS and available information. Therefore reducing the need for field surveys. Tephra is not included in the NZLRI as a lithology occurring on Emerald Hills station.

Because of the broad scale nature of the erosion information provided in the NZLRI it was necessary to make assumptions about the likely erosion in relation to slope. These

assumptions were based on a knowledge of the physical characteristics of the land and on the relationships between soil slip erosion and site factors (namely slope angle) discussed earlier in this thesis.

The banded mudstone (Mb) on Emerald Hills station is mapped on the NZLRI as mainly F slopes having moderate sheet and slight soil slip erosion. It is known from field inspection that much of the Mb has more moderate to severe soil slip erosion. The slope information from the TIN shows there are considerable areas of less than 26o (F) slopes.

For the purpose of this project it is assumed that A-D slopes will generally have slight soil slip and sheet erosion and therefore, are mapped as VIe1. The steeper (E) slopes have moderate erosion and are mapped as VIe7. More severe sheet or soil slip erosion occurs on F+G slopes that are mapped as VIIe2.

The only adjustment in the description of the units describing the sandstone was to delineate them according to more defined slope classes. VIe10 is mapped on slopes less than 25o (A-E); VIIe9 on 25-35o (F) slopes; and VIIe17 on slopes over 35o (G).

To reclassify the units on the jointed mudstone in more detail, assumptions had to be made about the land within each unit mapped on the NZLRI -

Where the erosion is slight-

A-D slopes are mapped as	VIe1
E " " " "	VIe6
F+G " " " "	VIIe1;

where the erosion is moderate-

A-E slopes are mapped as	VIe6
F " " " "	VIIe1
G " " " "	VIIe3;

where earthflow erosion is mapped as severe
and gully erosion is mapped as moderate-

A-C slopes are mapped as	VIe6
D+E " " " "	VIIe1
F+G " " " "	VIIe3.

In comparing the revised LUC map with the NZLRI LUC map (Figure 7.4) it can be seen that the GIS allocates LUC units with improved detail. This is due to the more

In comparing the revised LUC map with the NZLRI LUC map (Figure 7.4) it can be seen that the GIS allocates LUC units with improved detail. This is due to the more detailed slope information. The effect that the scale of the lithology information has on the mapping is evident.

The aim was to produce a LUC map of a scale closer to that of the farm plan. This has been achieved although it is difficult to compare the revised map of LUC units with the farm plan (Figure 7.5) because of the amount of land mapped on the farm plan as having a tephra cover resulting in some additional units (Table 7.3).

Descriptions for GDC Farm Plan LUC Units			
LUC Unit	Lithology	Slope	Erosion
IIs1	Alluvium	A	Nil
IIIw1	Alluvium	B	Nil to 1G
IVe3	Taupo Ash on Mudstone, and Alluvium	C+D	Nil
IVs1	Low-lying stone, alluvial terraces	C+D	Slight deposition
VIe1	Jointed or Banded Mudstone	D+E	1G
VIe3	Taupo Ash on Mudstone	D+E	1eF, 1G, 1Tg
VIe6	Jointed, Crushed and Massive Mudstone	D,E,F	1eF, 1G, 1Su
VIe7	Banded Mudstone	E+F	1eF, 1G, 1Su
VIe8	Taupo Ash on Mudstone	E+F	1sSl, 1G, 1eF
VIIe1	Jointed and Crushed Mudstone	E+F	1-2G
VIIe2	Banded and Massive-Jointed and Crushed Mudstone	F+G	1-2sSl, 1G
VIIe3	Crushed Mudstone	G	" "
VIIe9	Banded Sandstone	F	2eF, 1G
VIIe14	Crushed Mudstone	D+E	1sSl
VIIe16	Banded and Massive Mudstone	G	2-3eF, 2-3G, 2-3Su, 2sSl
VIIe17	Banded Sandstone	G	3-4sSl
VIIe20	Bentonitic Mudstone	E	1sSl
			3G, 2eF

Table 7.3 Description of the LUC units mapped on the GDC farm plan

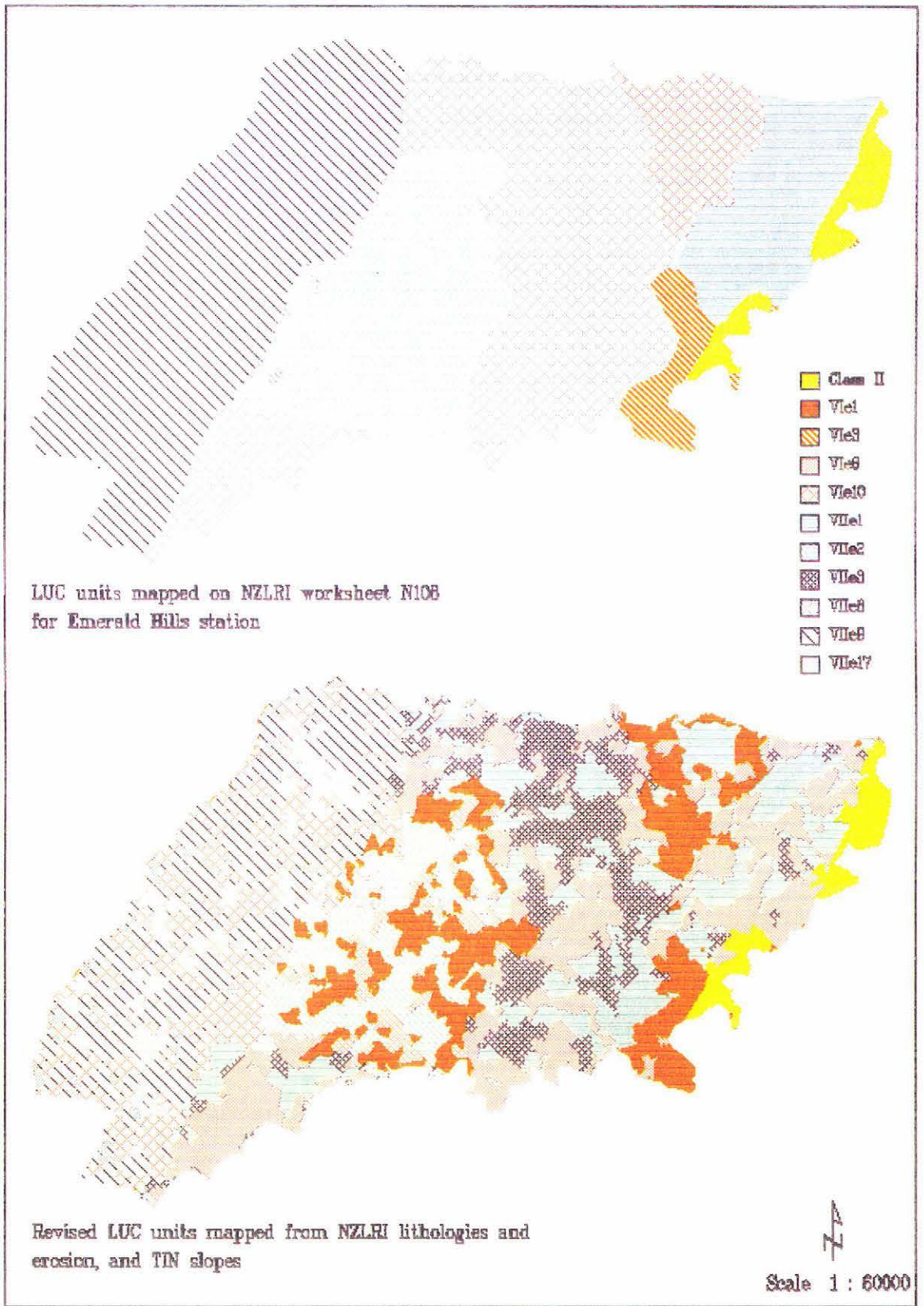


Figure 7.4 A comparison of the revised LUC mapping with the NZLRI

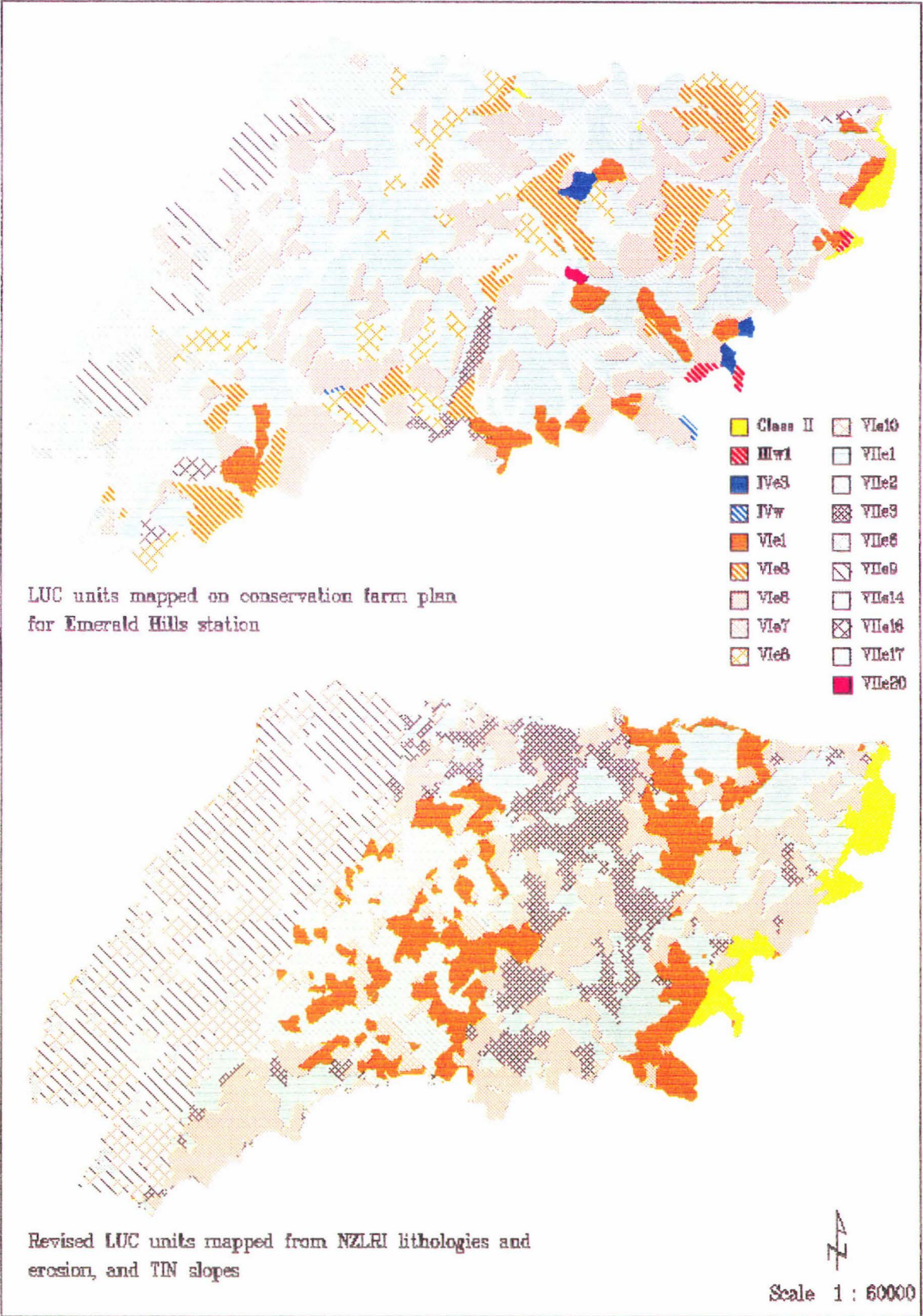


Figure 7.5 A comparison of the revised LUC mapping with the GDC farm plan.

7.4.2 Updating the revised LUC units using TIN generated slope aspect information

On the basis of the analysis completed earlier in this study, it was decided that aspect could help identify areas of land more susceptible to erosion and therefore, more limited in their use.

By intersecting the layer of LUC units derived from the previous section with the aspect layer, those slopes that occurred on the more erosion prone aspects (NE, N, NW, E) could be identified. These were then assigned a LUC unit that described land with one degree worse erosion status (Table 7.2).

The result is a slightly more complex map (Figure 7.6). The major reason for the variation in LUC mapping between the revised LUC map and the farm plan, is the scale of lithology and erosion information. The lithologies mapped on the farm plan produce a greater complexity of unit mapping. More units are used on the farm plan. IVe3, VIe3, VIe8 are mapped on tephra and VIIe14 and VIIe20 are mapped where slump or gully erosion is severe. This only occurs in small areas.

The purpose of land use mapping is to delineate areas of land that are the same or similar in their attributes and require the same management practices. In keeping with this, the farm plan delineates landforms (land components) that have consistent physical attributes. Only one unit is assigned to each land component. It is accepted that there will be small areas of other units within the delineated area that are considered to be too small to be mapped (and managed) as separate units (Figure 7.7). The GIS method does not identify land components but identifies the unit according to defined criteria. This can result in very small units or units unrelated to land form boundaries (Figure 7.7).

By overlaying the Cyclone Bola soil slips it can be seen that the revised LUC mapping has been successful in identifying the areas of land which are the most prone to soil slip erosion (Figure 7.8). On the jointed mudstone most of the soil slip occurs on unit VIIe3 and on the banded mudstone it is almost totally restricted to unit VIIe16. On the

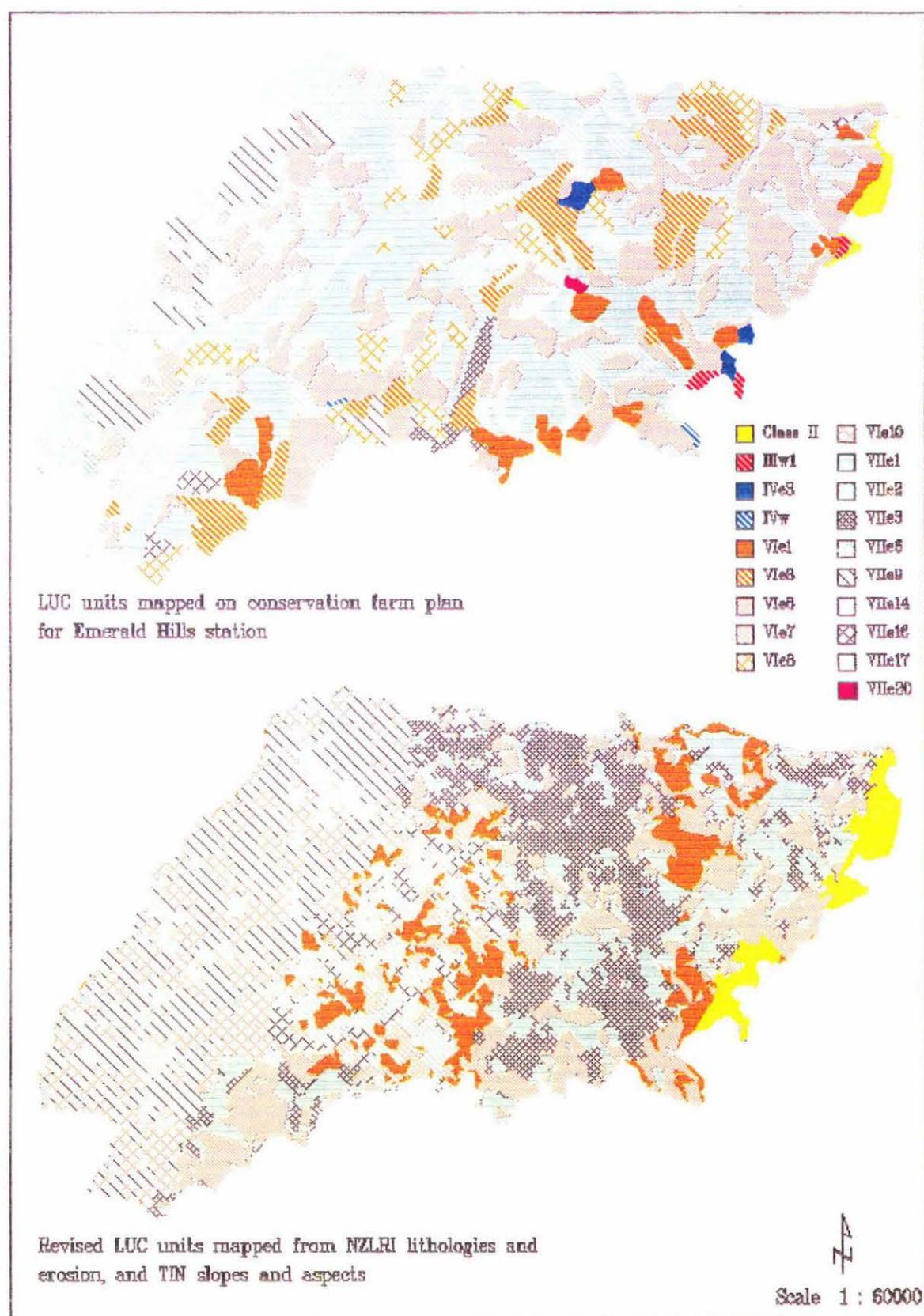
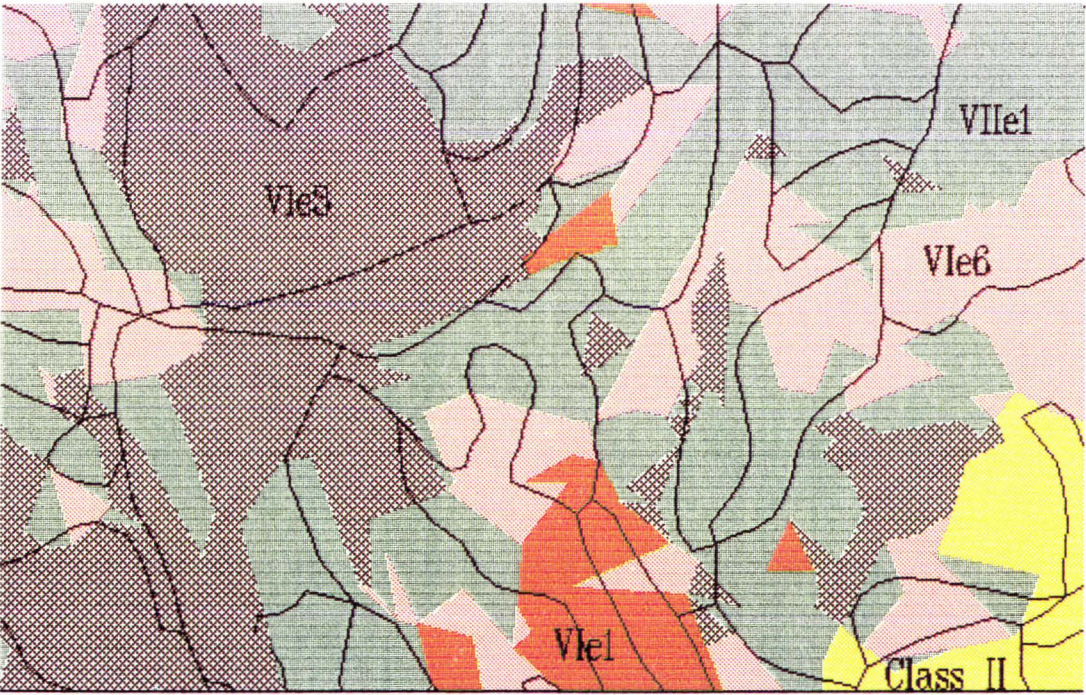


Figure 7.6

A comparison of the LUC mapping, further updated by the inclusion of slope aspect information, with the farm plan



LUC units mapped on conservation farm plan of Emerald Hills station



LUC units mapped from NZLRI inventory and TIN slopes and aspects overlaid with farm plan LUC boundaries

Figure 7.7 GDC farm plan LUC units are assigned in relation to landforms whereas the GIS method assigns them according to set criteria for lithology, slope and erosion.

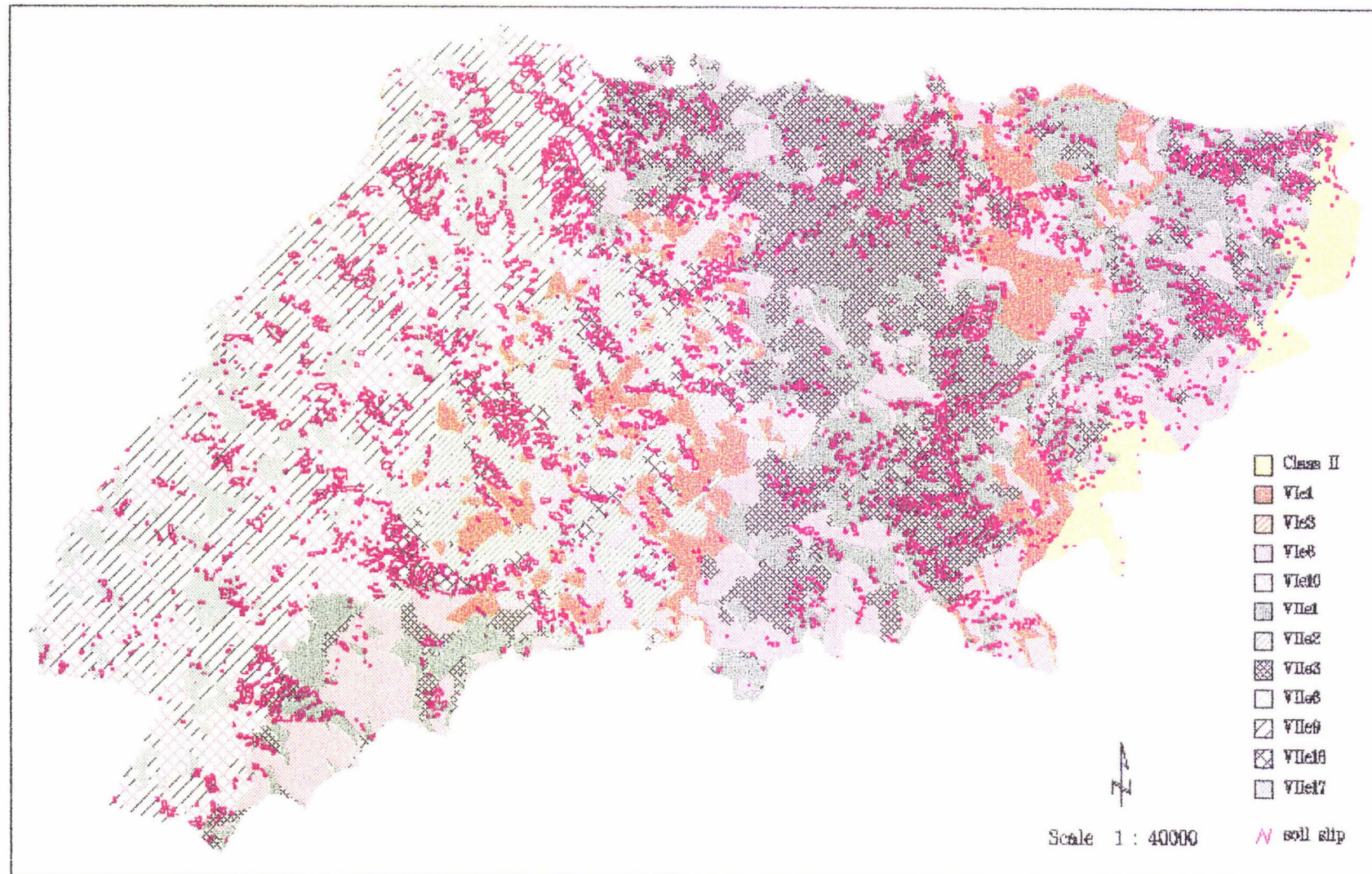


Figure 7.8 The distribution of Cyclone Bola soil slip on the revised LUC map

sandstone most of the soil slip occurs on VIIe9. This demonstrates the role that LUC units have in describing the lands versatility. VIIe17 is more limited in its use because of the steepness of the south- or west-facing slopes. Because of this steepness and the combined factors of less favourable microclimate and poor fertility of the sandstone, the land has been allowed to convert to natural bush. This vegetation protects the slopes from serious erosion. The warmer, predominantly northeast-facing slopes of VIIe9 maintain a pasture cover. They are less steep than the slopes of unit VIIe17 but, it has been shown earlier in this study that slopes of this aspect have more soil slip than slopes of southerly or westerly aspects.

There is only so much improvement that can be obtained using the scale of information available on the NZLRI and the fixed criteria method of this study. The revised LUC mapping method attempts to improve the scale of the LUC information from the NZLRI by predicting the likely unit based on assumed relationships between lithology, slope and erosion. While it does not produce a LUC map similar to the farm plan it does provide better information about the types of land on Emerald Hills station than the NZLRI.

For detailed conservation planning it may always be necessary to carry out field surveys. The methods used in the above exercise demonstrate how improved LUC information can be obtained for catchment- or farm-scale planning where it is necessary to know the extent of certain types of land, and farm plans do not exist. For example, to tender for forest establishment funding under the East Coast Forestry Project, 1993, information relating to the extent of the units within Class VII land (category 2 and 3 as defined in 'The Red Report') is necessary. Although a successful tender is reliant upon a number of factors, a property with more than 60% of Class VII land is qualified to tender. For the projects conservation objectives of increased employment opportunities and financial return to the economy high initial stocking rates of considered necessary. The units within Class VII are grouped according to a required initial stocking rate to qualify for tender.

Group A, requiring a minimum initial stocking rate of 1250 stems per hectare, includes units VIIe1, 2, 4, 6, 8, 9, 10, 11, 17, 19 & 21.

Group B, which has a minimum initial stocking rate of 1500 stems per hectare, includes units VIIe3, 5, 7, 12, 13, 14, 15, 16, 18 & 20.

Preference for funding is given to those tenders with a more intensive planting regime, that is more Group A land (MOF, undated)..

The NZLRI LUC information does not provide for a very detailed delineation of these units (89% of Emerald Hills station is mapped as Group A, 0% as Group B). More detailed inventory information provides a more reliable estimation of the extent of these units. When LUC units are ascertained using the revised LUC information 34% of the farm is mapped as Group A and 31% as Group B. The farm plan maps 56% as Group A and 6% as Group B.

7.5 DISCUSSION

The LUC classification is a satisfactory method for describing the proneness of land in the East Coast region to soil slip erosion but a more detailed map of LUC units is necessary for land management at the catchment or farm scale.

The NZLRI information can be improved using a GIS and set criteria based upon assumed relationships between lithology, slope and erosion.

The revised LUC information produced in this study is more suited to broad scale planning than farm management. Units are often very small or not coincidental with landform boundaries. These are not easily incorporated in farm management practices.

Generalisation of the units in terms of landscape boundaries, as is done on farm plans, can be achieved. It would require the compilation of a GIS layer of landform boundaries delineated from aerial photographs. There are other GIS, not available for this project, in which geometrically corrected aerial views of the study area can be viewed on the screen. Interactive delineation of landforms and an up-to-date inventory of vegetation and some forms of erosion can then be carried out in the office. The dominant LUC unit(s) within each delineated area can be determined by querying the information stored in spatially related feature attribute tables.

To improve the LUC mapping beyond that of the NZLRI more detailed lithology and erosion information is necessary.

CHAPTER VIII

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

The objects of this study were to;

- delineate soil slip erosion on Emerald Hills station following Cyclone Bola, 1988 using remotely sensed information;
- determine any relationships between the distribution of that soil slip and site factors;
- investigate the success with which the Land Use Capability mapping system describes the proneness of the land to soil slip erosion;
- attempt to improve the detail of the New Zealand Land Resource Inventory Land Use Classification.

8.1 CONCLUSIONS

Geographic Information Systems and remotely sensed data can assist in resource management by providing timely, and relatively accurate, information without lengthy field survey.

SPOT panchromatic satellite imagery and digitally scanned black and white aerial photographs of Emerald Hills station were compared for their ability to easily and accurately delineate areas of soil slip following Cyclone Bola, 1988. Aerial photography was found to have more potential to delineate soil slips than satellite imagery although neither satellite nor aerial photograph delineated all soil slips which were discernible by eye. Small areas of bare ground ($<4\text{m}^2$) were not detected due to the low reflectance values associated with their shallowness. In using the clustering method of classification some areas were misclassified because of the manipulation of the reflectance range assigned to bare ground. Satellite imagery can quickly provide information for a regional assessment. It was easy to register it to the New Zealand metric grid being used to align all layers of information in this GIS. But, 30% less bare ground was identified on this imagery in comparison to aerial photography.

Low sun angle at the time of the satellite image acquisition caused shadowing and a variation in reflectance values on areas of the same surface cover, as is discussed by Trotter *et al.* (1989). Therefore, it was difficult to assign a range of reflectance values to a surface cover for an accurate classification of the image as a whole.

Aerial photographs could not be registered to the topographic grid with the same ease or accuracy as the satellite imagery. This was because of the distortion in the photograph due to the tip and tilt of the camera during the flight and the terrain variability which also distorts the image, especially further from nadir (directly beneath the camera). This distortion is difficult to correct on the software available for this project. The use of orthophotos would overcome this problem. There was less variation in reflectance values for each landcover class within each photograph than on the satellite image. The differences in reflectance values for landcover classes on some photos (due to reflectance variation between flight paths) meant that each photo had to be processed separately, requiring more time than the satellite image.

This study found that it was not possible to differentiate vegetation types on scanned black and white photos. Others recommend colour infrared photography for the classification of surface vegetation, but it was not available for this study.

Ground checking ascertained that the 6.1% of the farm identified as soil slip on the aerial photographs was more accurate than the 4.5% on satellite imagery.

Conversion of the classified aerial imagery from raster to vector data structure enabled a map of soil slip following Cyclone Bola to be included in the GIS database. By incorporating this information with that relating to other physical characteristics of the land on Emerald Hills station it was possible to determine what relationships existed between those characteristics and the distribution of the soil slips.

As slope angle increases there is also an increase in the amount of soil slip until a slope angle of 30° above which there is no increase in density of soil slip. There is no

noticeable critical slope angle below which there is no soil slip. Some soil slip occurred on slopes of all steepness.

There is a relationship between the density of soil slip and the underlying rock type with mudstone, particularly jointed mudstone, being more prone to soil slip erosion than sandstone. There is less soil slip on surfaces underlain by tephra. These slopes are predominantly of low slope angle and are restricted to the broader ridges at lower altitudes.

Northerly- and easterly- facing slopes had the greatest density of soil slips following Cyclone Bola suggesting a relationship between the incidence of soil slip and the amount of spectral radance. The order in decreasing density is NE, N, NW, E, W, SE, SW, S. This study has not identified a reason for the predominance of soil slip on slopes of northerly and easterly aspect. Neither slope angle or rock type could be attributed to the cause of greater soil slip density.

The resolution of the contour data (20m) did not allow the identification of small changes in the terrain. It may be possible that the occurrence of soil slip is related to microtopographical features within a larger slope.

The Land Use Capability units mapped for the soil and water conservation farm plan of Emerald Hills station were found to be satisfactory at describing the distribution of soil slip erosion following Cyclone Bola. However, many regional councils do not have the majority of their regions mapped at a sufficiently large scale (e.g. as farm plans) for effective land use planning.

Until more detailed DEMs are available to facilitate automated mapping of land components and land resource information, the NZLRI is the only nationally available source of land resource and land use capability information. This project has developed methodology which can be used by land planners to improve the detail of mapping of the NZLRI Land Use Capability information. It involves the inclusion of more detailed resource information such as slope angle and aspect derived from 20m digital contour

by a digital elevation model. A map of detail similar to that of the farm plan LUC mapping was produced.

Although the definition of LUC units on the GIS, according to set criteria, produced a satisfactory map, it was seen that the final resolution of the units depends on that of the input data. Where the areas of input information are related to data points of considerable spacing they do not always coincide with landform boundaries. Areas of consistent slope angle or slope aspect were determined by a triangular irregular network from points of at least 20m spacing. This resulted in areas with straight line boundaries not always coincidental with landform boundaries. More detailed contour data (and DEM) would result in the delineation of LUC units that are more closely related to landscape components.

To create a map in the same way that the farm plan LUC units were mapped could be done by delineating the landcomponents on an image and then determining the LUC units within. The dominant unit (or units) may then be identified and land management practices applied accordingly.

8.2 SUGGESTIONS FOR FUTURE WORK

For very detailed investigations into the distribution of erosion (and other resource information) orthophotographs or low altitude multispectral imagery may prove to be easier to process and more geographically correct sources of information. Multispectral imagery has been found by others to be very useful for the classification of surface vegetation types.

A DEM of higher resolution may be more useful in investigating the cause of the greater density of soil slip on NE, N, NW and E aspects. This may be related to microtopography or to soil physical conditions that have not been included in this study. While field surveys may be required to obtain this information, GIS will facilitate the interpretation of its role in slope stability.

Further research is required to produce less expensive, and more detailed DEMs which will facilitate the automatic delineation of land components. More detailed mapping of resource information (rock type, erosion) is also necessary to automatically map LUC units at the same scale as farm plans. Although, the development of land attribute-landscape models may offer an alternative method of interpreting LUC units.

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APPENDIX I

TEPHRA ANALYSES

Sheryls Samples:

Sample 1) >80% of grains in the nonmagnetic separate are fresh, angular, and vesicular rhyolitic glass shards. Modal mineralogy of magnetic separate:

Orthopyroxene	59%
Clinopyroxene	36%
Hornblende	3.5%
Cummingtonite	1.5%

Sample 2) 23% clear rhyolitic glass shards in nonmagnetic separate. Modal mineralogy of magnetic fraction:

Orthopyroxene	74.5%
Clinopyroxene	19%
Hornblende	5.5%
Cummingtonite	1%

Sample 3) 11% glass shards in nonmagnetic separate. Modal mineralogy of magnetic separate:

Orthopyroxene	61.5%
Clinopyroxene	31.5%
Hornblende	4.0%
Cummingtonite	3.0%

Sample 4) >90% angular and vesicular glass shards in nonmagnetic fraction. Modal mineralogy of magnetic fraction:

Orthopyroxene	56%
Clinopyroxene	37%
Hornblende	4%
Cummingtonite	3%

Conclusions:

- a) All samples are tephra. Samples 1 and 4 are very pure whereas samples 2 and 3 are more dispersed within other sediment.
- b) The modal ferromagnesian mineralogy indicates that all the samples are likely to be of the same tephra.
- c) The modal ferromagnesian mineralogy is consistent with the field identification of the tephra as the Waiohau Tephra.
- d) Electron microprobe analysis of the glass shards will possibly further confirm the identification of the tephra.

sheryl	1	2	3	4	5	6	7	8	9	10	Menn
SiO ₂	78.68	78.453	76.518	80.202	79.669	79.6	78.154	76.557	78.702	76.425	78.296
TiO ₂	0.2	0.063	0.036	0.114	0.137	0.132	0.13	0.117	0.141	0.124	0.119
Al ₂ O ₃	12.1	11.896	11.995	11.979	12.126	11.848	11.74	11.672	11.982	11.523	11.886
FeO	0.837	1.048	0.762	0.888	0.846	0.916	0.956	0.899	0.751	0.725	0.863
MgO	0.17	0.165	0.161	0.197	0.095	0.083	0.111	0.107	0.113	0.087	0.129
CaO	0.835	0.723	0.75	1.282	0.737	0.795	1.044	0.737	0.621	0.785	0.831
Na ₂ O	4.101	4.118	3.68	3.842	3.905	3.941	4.049	3.68	3.914	3.86	3.909
K ₂ O	3.418	3.386	4.169	3.414	3.206	3.163	3.006	3.41	3.369	3.065	3.361
Cl	0.143	0.113	0.159	0.198	0.187	0.243	0.186	0.235	0.169	0.224	0.186
Total	100.484	99.965	98.23	102.116	100.908	100.721	99.376	97.414	99.762	96.818	99.579
SiO ₂	78.301	78.480	77.897	78.540	78.952	79.030	78.645	78.589	78.890	78.937	78.626
TiO ₂	0.199	0.063	0.037	0.112	0.136	0.131	0.131	0.120	0.141	0.128	0.120
Al ₂ O ₃	12.042	11.900	12.211	11.731	12.017	11.763	11.814	11.982	12.011	11.902	11.937
FeO	0.833	1.048	0.776	0.870	0.838	0.909	0.962	0.923	0.753	0.749	0.866
MgO	0.169	0.165	0.164	0.193	0.094	0.082	0.112	0.110	0.113	0.090	0.129
CaO	0.831	0.723	0.784	1.255	0.730	0.789	1.051	0.757	0.622	0.811	0.833
Na ₂ O	4.081	4.119	3.746	3.762	3.870	3.913	4.074	3.778	3.923	3.987	3.925
K ₂ O	3.402	3.387	4.244	3.343	3.177	3.140	3.025	3.501	3.377	3.166	3.376
Cl	0.142	0.113	0.162	0.194	0.185	0.241	0.187	0.241	0.169	0.231	0.187
Norm tot	100	100	100	100	100	100	100	100	100	100	100

VARIATION MATRIX

of 6 samples

with 8 elements

Numbers above unit diagonal are SIM. COEFF, below are COEFF. of VARIATION

Taupo(all) Okataina Rotoma Waiohau Rotorua sheryl

Taupo(al	--	0.769	0.752	0.806	0.914	0.774
Okataina	16.322	--	0.947	0.946	0.818	0.967
Rotoma	19.029	5.787	--	0.902	0.790	0.940
Waiohau	14.216	5.791	8.465	--	0.855	0.949
Rotorua	9.160	15.309	17.286	11.673	--	0.817
sheryl	15.869	2.380	4.850	4.551	13.766	--

Comparison of 6 samples completed

Sheryls Tephra:

The glass analyses of your tephra indicate:

- 1) The tephra is Okataina sourced
- 2) The tephra is best correlated with either the Waiohou or the Rotoma Tephra.

In my opinion the glass chemistry of the Waiohou and the Rotoma Tephra is very similar and it is difficult to distinguish between them, although your average glass analysis has a slightly higher similarity coefficient with Waiohou Tephra. The presence of a small amount of cummingtonite in some of the samples is indicative of Rotoma Tephra, but the overall mineralogy is more indicative of the Waiohou Tephra.

It is possible that in your samples represent a mixed tephra combination of Waiohou and Rotoma Tephra.

Feel free to discuss this result with me anytime.

Shane Cronin